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FINAL REPORT

STRIP CELL TEST AND EVALUATION PROGRAM

BY

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W. F. Bell  
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UNITED TECHNOLOGIES CORPORATION  
Power Systems Division

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Contract NAS3-20042

NASA Lewis Research Center  
Cleveland, Ohio  
Mr. Paul R. Prokopius, Project Manager



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In reply please refer to:  
Reference: OLM-085

25 September 1979

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Subject: NASA Contract No. NAS3-20042, Strip Cell  
Test and Evaluation Program, Final Report

References: (A) PSD Letter OLM-047 dated 27 October 1978  
(B) NASA-LeRC Letter 4243 dated 8 August 1979

Enclosure: Strip Cell Test and Evaluation Program Final Report,  
FCR-0945, NASA CR-159652

In accordance with the requirements of Paragraph C of the Reports of Work appendix to the subject contract, the enclosed report has been prepared by Power Systems Division, Fuel Cell Operations. Distribution of 104 copies have been made in accordance with the NASA supplied distribution list. This report was submitted for approval by Reference (A). Approval was received by Reference (B) and the report is hereby submitted completing the contractual requirements.

UNITED TECHNOLOGIES CORPORATION  
Power Systems Division

R. E. Martin  
Project Manager  
Advanced Fuel Cell System Program

FINAL REPORT  
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## FOREWORD

This final report describes the alkaline fuel cell research and development work completed under NASA contract No. NAS 3-20042 from 15 June 1976 through 30 April 1977.

The NASA Project Manager for this contract was Mr. Paul R. Prokopius. The contributions of Mr. Prokopius and other members of the Electrochemistry System Section staff at NASA Lewis Research Center are gratefully acknowledged.

Principal Power Systems Division personnel who directed the tasks performed in this program were:

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## ABSTRACT

This contract was the final one of a series of contracts with the long-range objective to reduce weight, extend life, and improve the performance characteristics of alkaline fuel cells for future space power systems. A unique feature of the advanced technology cells fabricated and tested under these contracts is the capability to evaporate the product water formed during the energy conversion reaction directly to space vacuum. A fuel cell powerplant incorporating these cells does not require a condenser and a hydrogen recirculating pump-water separator to remove the product water. This simplifies the fuel cell powerplant system, reduces weight and reduces system parasite power.

During this program, six,  $1/4 \text{ ft}^2$  ( $232.3 \text{ cm}^2$ ) active area single cells were fabricated and performance tested. In addition, endurance evaluation of a single  $1/10 \text{ ft}^2$  ( $92.9 \text{ cm}^2$ ) area cell initiated under NAS 3-19778 was continued. Also a two-cell plaque containing  $1/10 \text{ ft}^2$  ( $92.9 \text{ cm}^2$ ) area cells was fabricated and endurance tested.

A  $1/4 \text{ ft}^2$  ( $232.3 \text{ cm}^2$ ) active area cell configuration was identified where the performance effect of operating on propellant purity reactants was very small. This cell configuration has been incorporated into the design of a small lightweight power section sponsored by a Marshall Space Flight Center contract. A  $1/4 \text{ ft}^2$  ( $232.2 \text{ cm}^2$ ) active area single cell completed over 5000 hours of endurance testing.

Endurance testing of single cells and a two-cell plaque confirmed that the incorporation of a Teflon hydrogen flow field between the cell and product water removal unit retarded apparent electrolyte transfer which had limited the operating life of past cells. At the conclusion of this contract, 7824 hours of single cell and 859 hours of two-cell plaque testing were completed for a total of over 120,000 hours of testing during the entire program.

## I. SUMMARY

This document reports the activity and results of the final contract in a series of contracts of a long range research program to improve the life, weight, and performance of alkaline fuel cells. The advanced technology fuel cells are being developed to meet requirements of future NASA missions. These cells have a specific weight of 4 lbs/kW (1.8 g/W) which is half the weight of the cell incorporated in Power Systems Division PC17C Space Shuttle Powerplant.

### Objectives

There were three objectives of the work performed under this contract. The objectives were:

- Determine performance and endurance characteristics of the 1/4 ft<sup>2</sup> (232.3 cm<sup>2</sup>) active area cell configuration incorporated into the small lightweight powerplant design.
- Modify the 1/4 ft<sup>2</sup> (232.3 cm<sup>2</sup>) active area cell configuration to minimize the effect of propellant purity gases on performance.
- Establish that the introduction of a Teflon screen hydrogen flow field to the cell configuration extends operating life by eliminating electrolyte transfer between the cell and passive water removal unit.

### Scope

Six, 1/4 ft<sup>2</sup> (232.3 cm<sup>2</sup>) active area cells and one, two-cell plaque with 1/10 ft<sup>2</sup> (92.9 cm<sup>2</sup>) area cells were fabricated and tested. In addition, a 1/10 ft<sup>2</sup> (92.9 cm<sup>2</sup>) area cell which was fabricated and tested under contract NAS 3-19778 was continued on endurance.

### Results and Conclusions

A total of 7824 hours of single cell testing and 859 hours of two-cell plaque testing was completed. At the conclusion of the final contract, over 120,100 hours of testing had been completed during the entire program.

A 1/4 ft<sup>2</sup> (232.3 cm<sup>2</sup>) cell configuration demonstrated that the effect of propellant purity gases on cell performance was very small. The evaluation was conducted at current densities to 1000 ASF (1076.4 MA/cm<sup>2</sup>) with the hydrogen and oxygen being diluted with up to 0.5 percent Helium to simulate gases as might be obtained from space vehicle propellant tanks. Endurance testing of the cell configuration exceeded the 2500-hour design voltage requirement for a small lightweight powerplant out to 3700 hours with the test continuing for a total of 5000 hours.

The apparent transfer of electrolyte from the cell to passive water removal unit has been determined to result from the introduction of a wettable hydrogen flow field. Replacing this field in a single cell with a Teflon screen resulted in no evidence of electrolyte transfer during the entire 717 hours of testing. Characteristically evidence of the problem appeared within 300 hours on cells with a wettable flow field.

A two-cell plaque test demonstrated 740 hours of testing before evidence of electrolyte transfer between the cell and passive water removal appeared. This time period is more than two times the endurance capability of cells with a wettable field. Further testing will be required to confirm the wettable flow field hypothesis and to correct the problem which limits operating life of cells with passive water removal.

## II. INTRODUCTION

### Background

Power Systems Division (PSD) of United Technologies Corporation has been conducting a series of contracts under the direction of the Lewis Research Center of the National Aeronautics and Space Administration. The emphasis of these contracts is towards improving fuel cell technology for future space power applications.

The work accomplished under previous contracts has been reported in References 1 through 5. The final contract of this program is NAS3-20042.

Previous effort identified and demonstrated a lightweight cell design with improved performance and extended endurance.

A porous nickel plated polysulfone electrolyte reservoir plate (ERP) has been demonstrated which replaces the sintered nickel ERP in current space powerplants and is a major factor in reducing cell specific weight from 8 lbs/kW (3.6 g/W) to 4 lbs/kW (1.8 g/W).

A method of edge current collection has been demonstrated which allows the introduction of lightweight plastic features between cell assemblies in place of metal elements presently in use.

A gold-platinum catalyst cathode was developed which demonstrated increased cell performance and improved stability for long life. This cathode configuration has been incorporated into PSD's PC17C Space Shuttle Powerplant.

A cell structure was developed using a combination of fiberglass/epoxy and polysulfone laminations. This structure demonstrated reduced corrosion rates such that the build up of carbonates in the potassium hydroxide electrolyte was reduced by a factor of 3.

A passive water removal assembly has been demonstrated which eliminates the requirement for rotating machinery to remove the water generated during cell operation. This contributes to a powerplant design with reduced weight with a potential for higher reliability and extended endurance.

Cell designs have been demonstrated with active areas of  $1/10 \text{ ft}^2$  ( $92.9 \text{ cm}^2$ ) and  $1/4 \text{ ft}^2$  ( $232.3 \text{ cm}^2$ ) compared with the  $1/2 \text{ ft}^2$  ( $464.5 \text{ cm}^2$ ) cell incorporated in the Space Shuttle Orbiter powerplant. This allows an improved match for low power applications of the fuel cell. A multi-cell plaque configuration has been demonstrated with up to six cells arranged in a co-planner array within a common structural frame.

Polybenzimidazole and potassium titanate have been identified as materials for electrolyte matrices with a potential to extend cell life, and a structural resin with a low corrosion rate and the ability to operate at elevated temperatures has been identified.

Multi-cell plaques with dedicated flow fields and manifolds for all fluids did not exhibit the cell to cell electrolyte transfer which limited operating life of early plaques.

The apparent transfer of electrolyte between the cell and passive water removal unit was identified and found to result from the wettable hydrogen flow field.

#### Related Work

A program is underway at Power Systems Division with Marshall Space Flight Center to incorporate many of the technology advances demonstrated under the NASA-Lewis contracts. The work has resulted in the design of a small lightweight space powerplant with a nominal power rating of about 2 kW and a specific weight of 17.5 lbs/kW (7.9 g/W). The effort under the Marshall program will culminate in a demonstration of a 30 cell power section utilizing a cell with an active area of  $1/4 \text{ ft}^2$  ( $232.3 \text{ cm}^2$ ) operating with passive water removal.

#### Scope

Six,  $1/4 \text{ ft}^2$  ( $232.3 \text{ cm}^2$ ) active area cells were fabricated and performance tested to assist in identifying a configuration capable of operation on gases supplied from space vehicle propellant tanks. A single  $1/10 \text{ ft}^2$  ( $92.9 \text{ cm}^2$ ) area cell was continued on endurance from NAS 3-19778 and one two-cell plaque with  $1/10 \text{ ft}^2$  ( $92.9 \text{ cm}^2$ ) cells was fabricated and performance tested.

#### Relevance and Significance

The performance and endurance of lightweight cells with a 50 percent reduction in weight compared to cells in current space powerplants has been demonstrated. These cells operate with passive water removal which permits a powerplant design with reduced weight and extended operating life.

The cell configuration incorporated into the small lightweight powerplant design has been shown to be capable of operating on vehicle propellant purity gases and exceeding the 2500-hour design life voltage requirements.

Apparent transfer of electrolyte from the cell to the passive water removal unit has been observed. A discussion of the electrolyte transfer mechanism is presented in ref. 1, which indicates that the introduction of a wettable structure between the cell and passive water removal was the primary path for the transfer. Further testing is required to confirm the model and to correct the problem which limits operating life of cells with passive water removal assemblies.

### Purpose and Objectives

There were three objectives of the work conducted under contract NAS3-20042.

- Determine performance and endurance characteristics of the  $1/4 \text{ ft}^2$  ( $232.3 \text{ cm}^2$ ) active area cell configuration incorporated into a small lightweight powerplant design.
- Modify the  $1/4 \text{ ft}^2$  ( $232.3 \text{ cm}^2$ ) active area cell configuration to minimize the effect of propellant purity gases on performance.
- Confirm that the introduction of a Teflon screen hydrogen flow field to the cell configuration extends operating life by eliminating electrolyte transfer between the cell and passive water removal unit.

### Test Conditions

The performance evaluation tests were conducted in test stands originally built for the Apollo fuel cell program in 1963 and modified to meet the requirements of the current cells.

Performance evaluations were conducted at current densities to 1000 ASF ( $1076.4 \text{ MA/cm}^2$ ) on anticipated propellant purity gases which were simulated by diluting the reactants with up to 0.5% Helium.

Operating reactant pressure in the cell is approximately 16 psia ( $11 \text{ N/cm}^2$ ) at a nominal cell temperature of  $180^\circ\text{F}$  ( $82.2^\circ\text{C}$ ). A vacuum of 21.8 inches mercury ( $553.7 \text{ mm Hg}$ ) is maintained in the water cavity of the passive water removal assembly to achieve product water removal and maintain operating electrolyte concentration.

## III. TEST ARTICLE CONFIGURATIONS

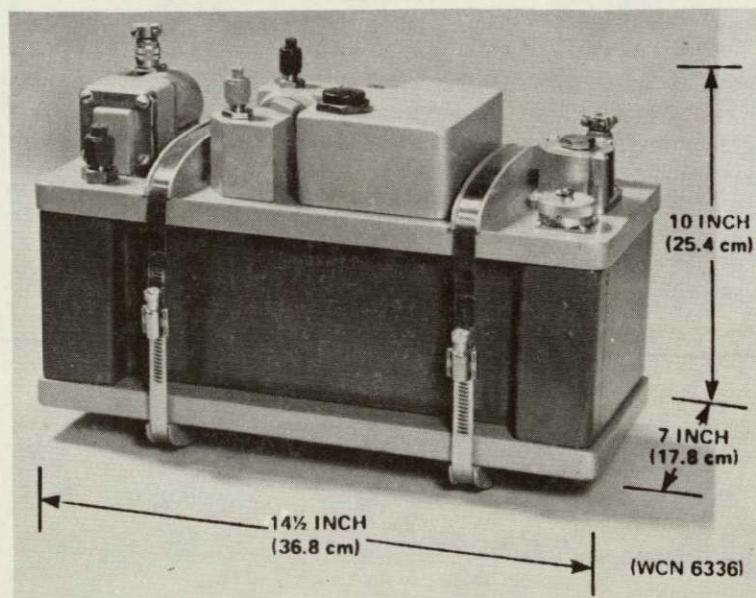
This section describes the single cell and two-cell plaque configurations tested during the program. There were three cell configurations evaluated during the program. Each are identified in the following sections. These test articles incorporate the following similar features.

- Strip cell, high length to width ratio
- Edge current collection
- Lightweight plastic cell features
- Passive Water Removal

The cell assembly consists of two sections, the unitized electrode assembly (UEA) and the passive water removal (PWR) unit. These two components can be either bonded together or mated with an elastomer gasket between them to affect the required seal.

A. One Quarter Square Foot ( $232.3 \text{ cm}^2$ ) Cell Definition

A new cell configuration was incorporated into the design of a small lightweight powerplant based upon requirements supplied by Marshall Space Flight Center under contract NAS8-30637. Figure 1 shows a model of the resultant powerplant. The significant powerplant design requirements are presented in Table I. The cell incorporated into the powerplant contains many of the fuel cell technology advances which have resulted from the NASA-Lewis program.



- 34,  $0.25 \text{ FT}^2$  ( $232.3 \text{ cm}^2$ ) CELLS
- PASSIVE WATER REMOVAL
- CIRCULATING COOLANT
- VOLUME -  $0.59 \text{ FT}^3$  (16.7 Liters)
- WEIGHT - 48 LBS (21.8 Kg)

Figure 1. Small Lightweight 2.0 kW Powerplant

TABLE I

## Lightweight Powerplant Design Requirements

●	Power Output (kW)	
	. Nominal Range	0.5 - 2.0
	. Peak	3.5
●	Voltage (Volts)	
	. Nominal Power Range	32.5 - 24.0
	. Peak Power	18.0
●	Reactant Supply Pressure (psia)	
	. Hydrogen	16.8 - 21.4 (11.6 - 14.8 N/cm <sup>2</sup> )
	. Oxygen	28.1 - 33.6 (19.4 - 23.2 N/cm <sup>2</sup> )
●	Reactant Purity	Propellent Grade (Helium diluents to 0.3%)
●	Endurance (Hours)	2500

The cell defined for the application has an active area of  $1/4 \text{ ft}^2$  (232.3 cm<sup>2</sup>) with planar dimensions of 3 in. x 12 in. (7.6 cm x 30.5 cm). The cell configuration is shown in Figure 2. The salient features of the  $1/4 \text{ ft}^2$  (232.3 cm<sup>2</sup>) cell are as follows, and a complete description is presented in Table II.

- Gold-Platinum Catalyst Cathode
- Lightweight Nickel Plated Polysulfone Electrolyte Reservoir Plate
- Fiberglass/Epoxy-Polysulfone Hybrid Cell Edge Frame
- Porous Teflon Passive Water Removal Membrane
- Teflon Screen, Hydrogen, Coolant, and Product Water Flow Fields
- Electroform Nickel Oxygen Flow Field

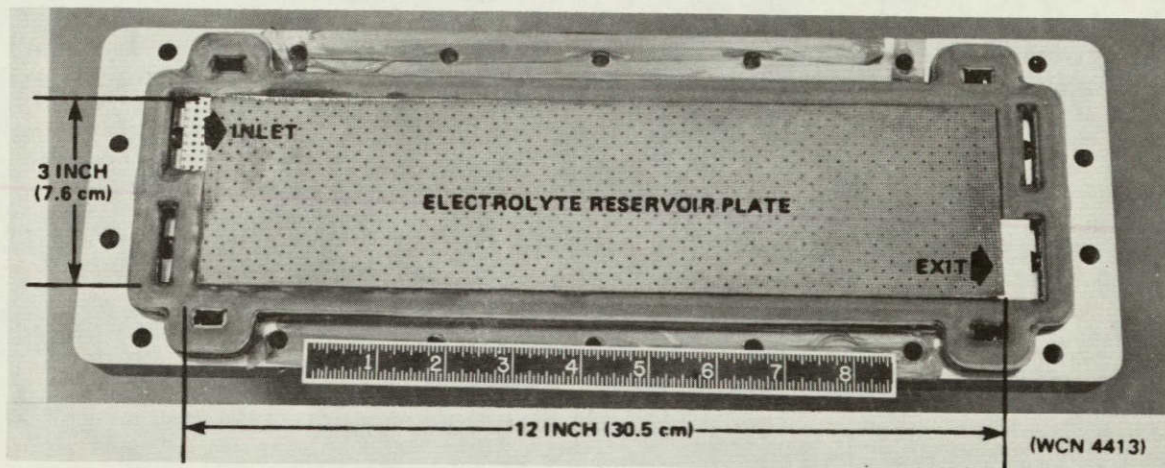


Figure 2. Unitized Electrode Assembly,  $1/4 \text{ ft}^2$  ( $232.3 \text{ cm}^2$ )

TABLE II

Cell Definition of  $1/4 \text{ ft}^2$  ( $232.3 \text{ cm}^2$ ) Configuration

Unitized Electrode Assembly

Anode - PtPd catalyst on silver plated nickel screen  
 Cathode - Au Pt catalyst on gold plated nickel screen  
 Matrix - Reconstituted asbestos  
 ERP - Nickel plated polysulfone - 30 mils (.76 mm) thick  
 Frame - Resin impregnated fiberglass

Passive Water Removal Assembly

Matrix - Reconstituted asbestos  
 ERP - Nickel plated polysulfone - 30 mils (.76 mm) thick  
 Membrane - Porous Teflon  
 Protective Screen - Silver plated nickel screen  
 Frame - Resin impregnated fiberglass

Cooler

Oxygen/Coolant Separator - Electro deposited nickel foil  
 Frame - Resin impregnated fiberglass

Flow Fields

$\text{H}_2$  - Teflon screen, 30 mils (.76 mm) thick  
 $\text{O}_2$  - Electrodeposited nickel foil - 2 mils (.05 mm) thick  
 $\text{H}_2\text{O}$  Vapor - Teflon Screen, 30 mils (.76 mm) thick  
 Coolant - Teflon Screen, 30 mils (.76 mm) thick

Nickel inlet reactant foils are used at both reactant inlets and on the PWR support screen at the hydrogen inlet. This feature prevents localized drying from the unhumidified reactants allowing water vapor diffusion to prevent port blockage. A sketch on the foil configuration is shown in Figure 3.

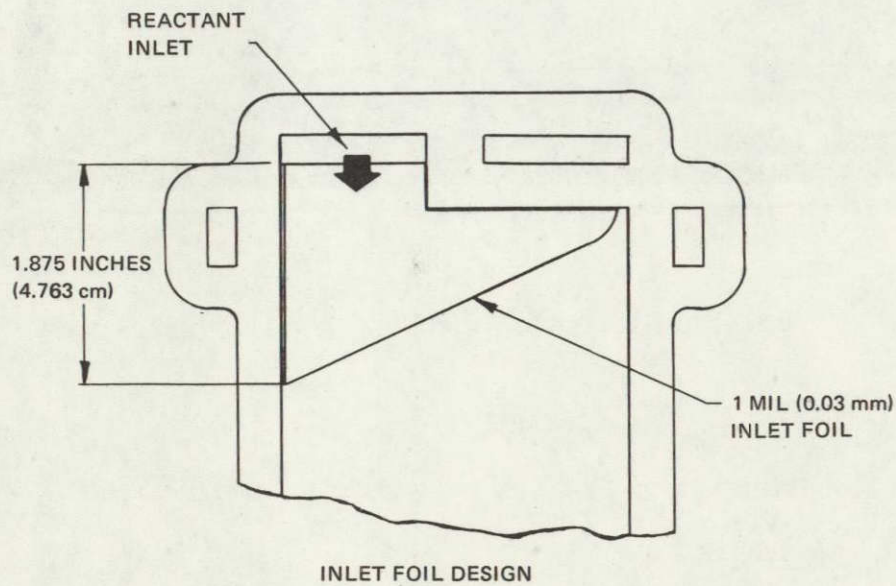


Figure 3. Reactant Inlet Foil Design

A second support screen was introduced between the PWR matrix and ERP. This provides a support for the matrix should there be some ERP shrinkage during fabrication of the PWR unit. An unsupported matrix cannot provide an effective seal against the pressure gradient required for product water removal. A sketch of the PWR design is shown in Figure 4.

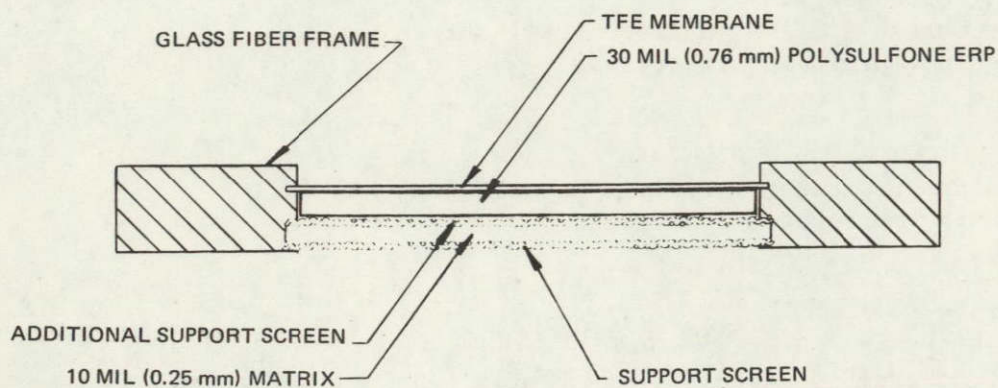


Figure 4. Passive Water Removal Unit Support Screens

There were six cells of the  $1/4 \text{ ft}^2$  ( $232.3 \text{ cm}^2$ ) active area configuration tested during the program. A detailed description of these cells is shown in Table III. A summary of the test results is presented in Section IV and a complete history of  $1/4 \text{ ft}^2$  ( $232.3 \text{ cm}^2$ ) cell testing is available in Appendix A.

TABLE III

Summary of Single-Cell,  $1/4 \text{ ft}^2$  ( $232.3 \text{ cm}^2$ ) Designs Evaluated

Cell Number	UEA Description	PWR Description	Oxygen Field	Hydrogen Field
1	Hybrid-Polysulfone Epoxy-Glass Fiber Frame PPF Anode 90 Au-10Pt Cathode 30 Mil(0.76mm) Polysulfone ERP 15% H <sub>2</sub> Access ERP at 176 Lt Hours 10 Mil (0.25mm) RAM	Epoxy-Glass Fiber Frame 10Mil(0.25mm) RAM 30 Mil (0.76mm) Polysulfone ERP Goretex Membrane 5 Mil (0.13 mm) Nickel Support Screen	Electroformed 3 Mil (.076mm) Ni, 15 Mil (.38mm) Field Depth	Machined Teflon 35 Mils (.89mm) Thick
2	Same as Cell 1 Installed 15% H <sub>2</sub> Access ERP at 778 Hours	Same as Cell 1	Same as Cell 1	Same as Cell 1 Installed Teflon Screen and Reactant Foils at 634 hours
3	Same as Cell 1 15% H <sub>2</sub> Access Polysulfone ERP	Same as Cell 1 5 Mil (0.13 mm) Nickel Support Screen Both Sides of Matrix	Same as Cell 1	Teflon Screen 30 Mils(0.76mm) Thick
4	Same as Cell 3	Same as Cell 3	Same as Cell 3	Same as Cell 3
5	Same as Cell 3	Same as Cell 3	Same as Cell 3	Same as Cell 3
6	Same as Cell 3	Same as Cell 3	Same as Cell 3	Same as Cell 3

### B. One Tenth Square Foot ( $92.9 \text{ cm}^2$ ) Cell Definition

The  $1/10 \text{ ft}^2$  ( $92.9 \text{ cm}^2$ ) single cell test unit was developed in earlier NASA-Lewis programs. A complete description can be found in ref. 1. Figure 5 shows a typical  $1/10 \text{ ft}^2$  ( $92.9 \text{ cm}^2$ ) cell. This cell configuration was incorporated into the Engineering Model System (EMS) design described in ref. 5. The cell has an active area of  $0.114 \text{ ft}^2$  ( $105.9 \text{ cm}^2$ ) with planar dimensions of 1.37 in. x 12 in. ( $3.48 \text{ cm} \times 30.5 \text{ cm}$ ).

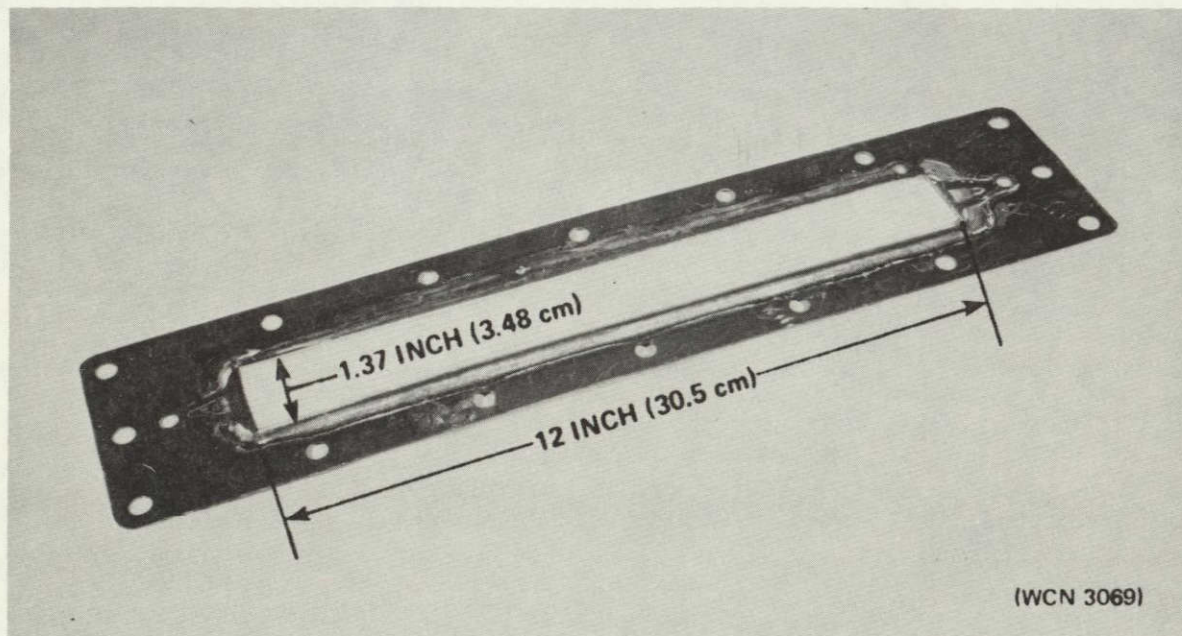


Figure 5.  $1/10 \text{ ft}^2$  ( $92.9 \text{ cm}^2$ ) Cell Configuration

This cell configuration was the primary test vehicle for cell structural material evaluations and electrode development testing. In the current program one  $1/10 \text{ ft}^2$  ( $92.9 \text{ cm}^2$ ) cell was continued on test to evaluate extended endurance capability. A description of cell tested is presented in Table IV. A summary of test results is presented in Section V and the history of performance testing is available in Appendix B.

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TABLE IV

Single Cell, 1/10 ft<sup>2</sup> (92.9 cm<sup>2</sup>) Design Evaluated

<u>Cell Number</u>	<u>UEA Description</u>	<u>PWR Description</u>	<u>Oxygen Field</u>	<u>Hydrogen Field</u>
46	Hybrid Polysulfone/ Epoxy-Glass Fiber Frame PPF Anode 90 Au-10Pt Cathode 30 Mil (0.76mm) Polysulfone ERP 10 Mil (0.25mm) RAM	Epoxy-Glass Fiber Frame 10 Mil (0.25mm) RAM 30 Mil (0.76mm) Polysulfone ERP Teflon Membrane	Electroformed Nickel. 15 Mil Screen (.38mm) Field	Teflon/ Screen

## C. Two-Cell Plaque Definition

This section describes the design of the single, two-cell plaque configuration evaluated during the program. Each cell in the plaque incorporated the same design features as the single cell described in Section IIIB and each cell is completely isolated from each other. The plaque incorporates independent fluid manifolding of all fluids for each cell. Complete isolation of each cell is achieved by bonding the plaque together as a complete unit. This was accomplished by bonding the center cell divider of each part together forming a continuous barrier between cells. Figure 6 shows the arrangement of the cells within the plaque.

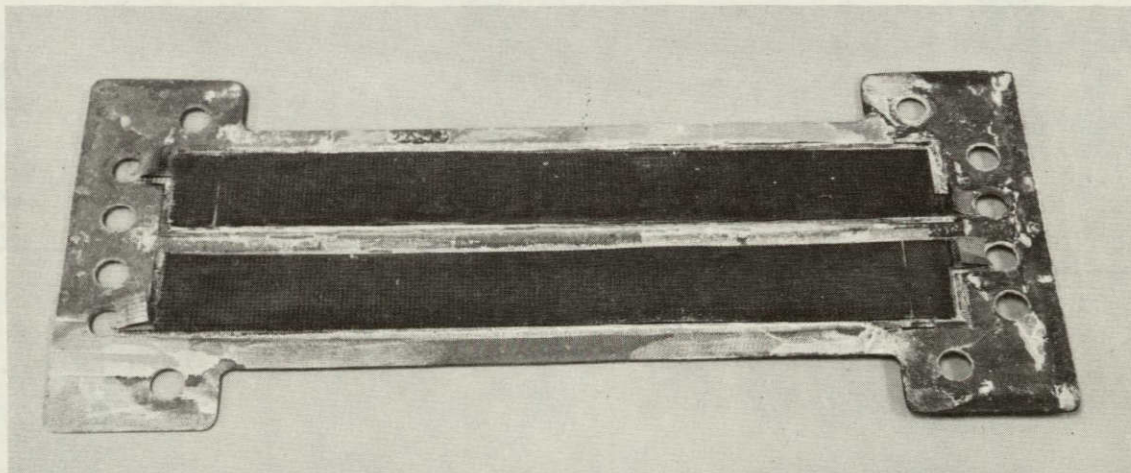


Figure 6. Two-Cell Plaque

(WCN-4015)

The two-cell plaque configuration tested in this program is described in Table V.

TABLE V

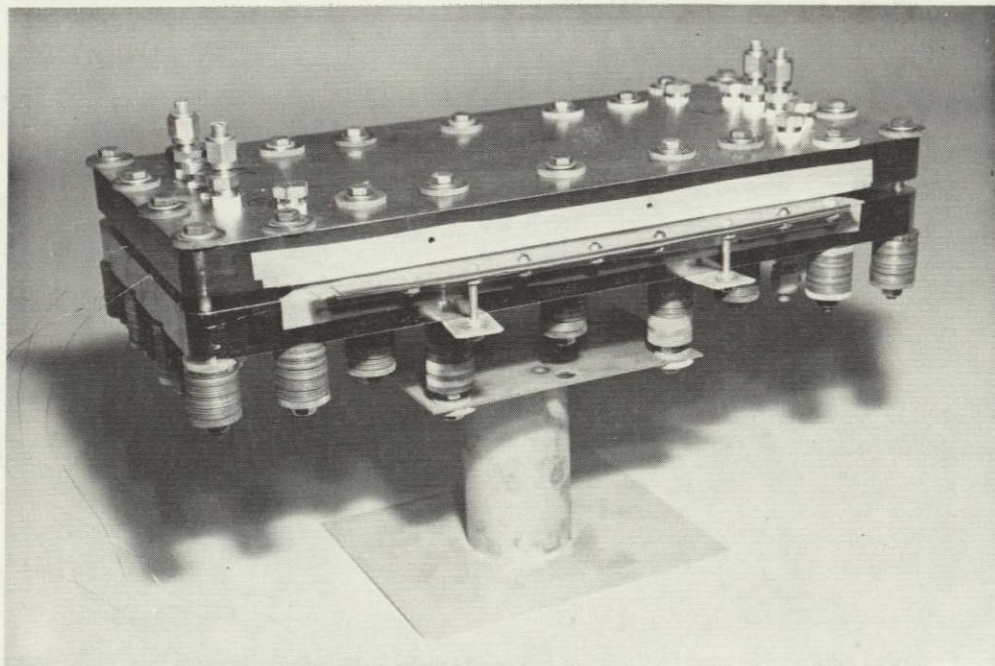
## Two-Cell Plaque Design Evaluated

<u>Plaque Number</u>	<u>UEA Description</u>	<u>PWR Description</u>	<u>Oxygen Field</u>	<u>Hydrogen Field</u>
4	Epoxy/Glass-Fiber Frame PPF Anode 90 Au-10 Pt Cathode 30 Mil Polysulfone ERP 10 Mil (0.25mm) RAM	Epoxy/Glass Fiber Frame 10 Mil (0.25mm) RAM) 22Mil(0.56mm) Polysulfone ERP Teflon Membrane	Electroformed Nickel, 15 Mil (.38mm) Field Depth	Teflon Screen

A discussion of the two-cell plaque No.'s 1, 2, and 3 can be found in reference 1.

A two-cell plaque set up for endurance testing is shown in Figure 7.

A summary of two-cell plaque test results is presented in Section V and a complete test history is available in Appendix B.



(WCN-3656)

Figure 7. Two-Cell Plaque Test Set-up

#### IV. DILUTED REACTANT INVESTIGATION AND PERFORMANCE DEMONSTRATION

The first objective of the  $1/4 \text{ ft}^2$  ( $232.3 \text{ cm}^2$ ) cell testing was to establish the performance characteristics of the new cell configuration incorporated into the small lightweight power section. A second objective was to modify the  $1/4 \text{ ft}^2$  ( $232.3 \text{ cm}^2$ ) cell geometry to define a cell configuration capable of operating on propellant grade reactants. The final objective was to demonstrate the endurance characteristics of the modified cell configuration.

##### A. Discussion of Test Results

Single cell test results on pure reactants demonstrated a performance level consistent with the small lightweight powerplant design requirements. The predicted performance was based upon previous NASA-Lewis  $1/10 \text{ ft}^2$  ( $92.9 \text{ cm}^2$ ) cell test results.

The performance response to helium diluted reactants was initially greater than expected. A carbonate analysis conducted on the fourth cell tested indicated a significantly higher carbonation of the electrolyte than could be attributed to normal frame corrosion products. Subsequent analysis of the reactants identified high levels of carbon monoxide and carbon dioxide in the reactant bottle supply which would account for the high carbonates. This contamination was apparently the cause of the high performance response to diluted reactants and inlet port plugging experienced during initial testing. Performance testing with non-contaminated diluted gases revealed a very small performance response consistent with expectations.

Diluted reactant testing indicated that the majority of the reduced performance was associated with the hydrogen electrode. The electrolyte reservoir plate (ERP) design was modified to increased reactant passage to the anode which improved scavenging of inerts from between the anode and ERP. Figure 8 shows that by increasing the hydrogen access area from 3 percent to 15 percent resulted in a 23 mV at 400 ASF ( $430.6 \text{ MA/cm}^2$ ) reduction in performance sensitivity to 0.5% Helium diluted reactant. The introduction of a Teflon screen hydrogen flow field further improved performance by 15 mV. The Teflon screen apparently improves hydrogen access to the anode.

As part of the diluted reactant testing, data was generated to determine reactant purge interval. This evaluation was conducted on 0.1% helium and 0.5% helium diluted reactants out to a current density of 400 ASF ( $430.6 \text{ MA/cm}^2$ ).

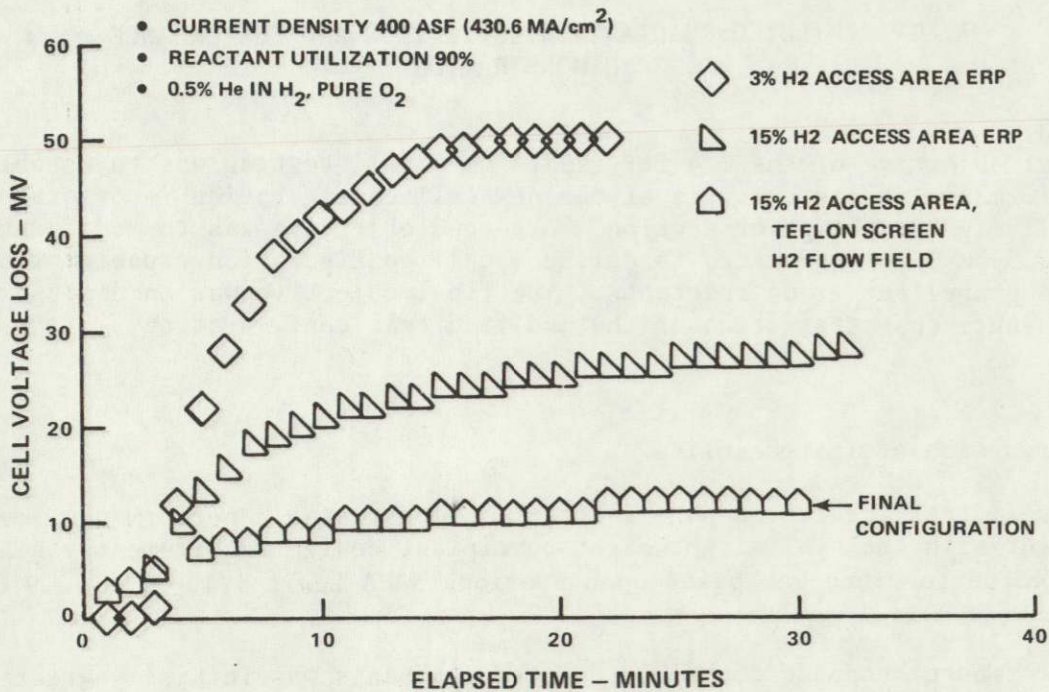


Figure 8. Performance Response to Helium Diluted Hydrogen

An endurance test of the final configuration cell was conducted to demonstrate long-term endurance capability. The test was conducted to a simulated mission profile which represented a power profile for the small lightweight powerplant design. Figure 9 shows that the cell performance exceeded performance design criteria and satisfied powerplant voltage requirements out to 3712 hours well beyond the 2500-hour design goal.

Detailed discussion of the 1/4 ft<sup>2</sup> (232.3 cm<sup>2</sup>) cell testing can be found in Appendix A.

#### B. Summary of Results

This section summarizes the results of testing on the new 1/4 ft<sup>2</sup> (232.3 cm<sup>2</sup>) active area cell configuration.

- Demonstrated a performance level consistent with the small 2.0 kW powerplant design.
- Established effect of diluted reactants on cell performance.
- Modified the 1/4 ft<sup>2</sup> (232.3 cm<sup>2</sup>) cell configuration to minimize the effects of diluents on performance.
- Exceeded the small 2.0 kW powerplant 2500 hour voltage requirements out to 3712 hours.

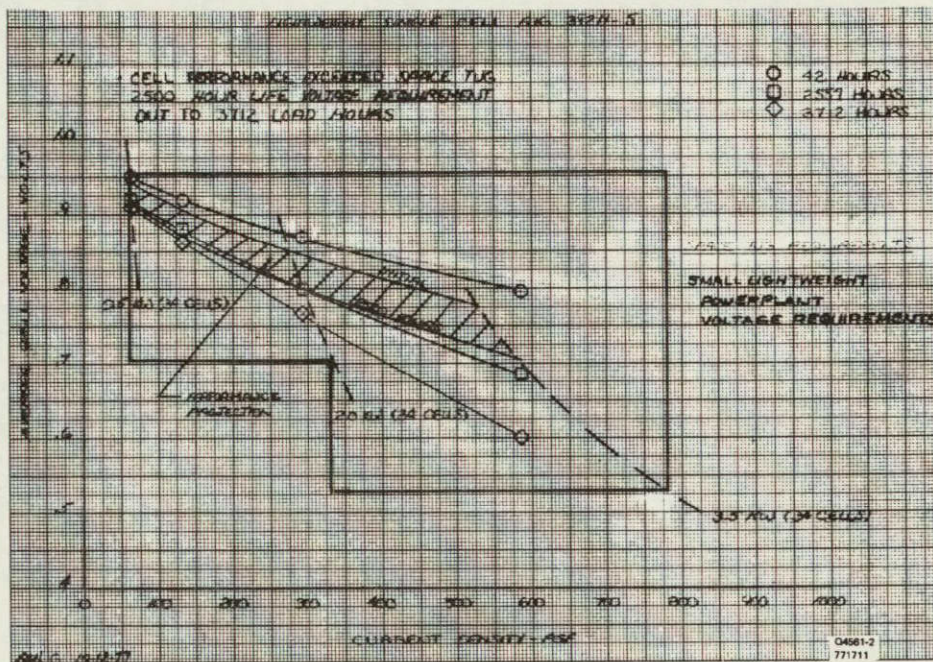


Figure 9. Performance Calibration

## V. FLOW FIELD CONFIGURATION CONFIRMATION

The apparent transfer of electrolyte between the cell and passive water removal assembly was found to be responsible for the reduced operating life of previous cells. The transfer was found to result from the introduction of a wettable hydrogen flow field (ref. 1) into these cells. Metal flow fields were used in these cells because of the weight and cost characteristics and low pressure loss. Preliminary test results from a cell containing a non-wettable flow field to prevent the electrolyte transfer were very encouraging. The objective of the work under the current contract was to demonstrate the extended endurance capability of a single-cell and two-cell plaque with Teflon hydrogen flow fields.

## A. Discussion of Test Results

A 1/10 ft<sup>2</sup> (92.9 cm<sup>2</sup>) single cell completed 717 hours of operation with a Teflon hydrogen flow field without any evidence of electrolyte transfer in the performance data. The inability to operate a cell at high electrolyte concentrations has been the primary symptom of cell electrolyte loss. The 717 hours is more than double the operating life of previous cells with wettable flow fields.

A two-cell plaque (TCP) was fabricated with a Teflon hydrogen flow field and tested to demonstrate that this modification extended operating life. TCP's in the previous program (ref. 1) were limited to approximately 300 hours. Up to 740 hours of operation were completed with no evidence of electrolyte transfer in two-cell plaque, No. 4 (TCP-4). An electrolyte excursion test at that time showed a slight droop in cell performance at setting a 40% wt. KOH concentration. This could be caused by carbonation of the electrolyte or an electrolyte inventory reduction. A carbonate analysis showed normal carbonation levels. On the basis of the electrolyte excursion test, a reduction in cell electrolyte inventory had occurred.

## B. Summary of Results

This section summarizes the results of the Teflon hydrogen flow field configuration testing.

Two-cell plaque test results indicating that electrolyte had transferred from the cell to PWR unit with a non-wettable flow field are inconclusive. Interpretation of the performance data may have been influenced by any of the following factors.

- Low initial cell electrolyte weight
- Reproducibility of cell hardware
- Hydrogen overpressure during testing

The first two factors could contribute to a marginal cell electrolyte fill at the commencement of testing. With time, normal electrolyte carbonation would produce a cell performance response at elevated electrolyte concentrations similar to a cell losing electrolyte. A physical loss of cell electrolyte from the cathode could have occurred with a hydrogen overpressure. During periods of unattended operation, hydrogen overpressures could have occurred.

Additional testing will be required to confirm that a non-wettable flow field will eliminate cell to PWR electrolyte transfer.

APPENDIX A

DETAILS OF ONE QUARTER SQUARE FOOT ( $232.3 \text{ cm}^2$ ) CELL EVALUATION TESTS

## APPENDIX A

DETAILS OF ONE QUARTER SQUARE FOOT (232.3 cm<sup>2</sup>) CELL EVALUATION TESTS

## Single Cell No. 1

The first test objective of single cell No. 1 was to acquire performance data on pure reactants for the new 1/4 ft<sup>2</sup> (232.3 cm<sup>2</sup>) cell configuration. A second objective was to determine the performance response to helium diluted reactants. Details of the cell construction are shown in Table II, Section IIIA. A total of 737 hours of testing was completed. The performance history of the cell is shown in Figure 10.

A performance calibration on pure reactants indicated a performance level consistent with the small 2.0 kW powerplant design. Results of the calibration are shown on Figure 11. As expected the effect of pure reactant utilization was very small.

Testing on reactants diluted with helium to simulate gases from vehicle propellant tanks resulted in significant reduction in cell performance. These tests were conducted with 0.5% helium diluted reactants at utilizations of 70 and 90 percent at current densities out to 600 ASF (645.8 MA/cm<sup>2</sup>). Because of the excessive performance reduction on diluents, cell testing was stopped at 176 load hours to install a new ERP configuration. In order to reduce the possibility of inert stagnation under the ERP, the hydrogen access area through the ERP was increased from 3% to 15 % by increasing the number of access holes and their diameter. Test results from the diluted reactant testing is shown on Figure 12. The increased access area ERP significantly reduced cell performance response to diluents. The cell performance improved anywhere from 10 mV at 600 ASF (645.8 MA/cm<sup>2</sup>) to 25 mV at 400 ASF (430.6 MA/cm<sup>2</sup>) and 90 percent reactant utilization.

Upon completion of diluent testing at 260 load hours, endurance operation at 100 ASF (107.6 MA/cm<sup>2</sup>) on pure reactants was initiated. During this period there was no significant performance reduction.

A summary of electrolyte excursion tests, shown on Figure 13, indicated a normal performance response through 638 load hours. At 713 hours there was a slight performance droop upon setting 40% wt KOH electrolyte concentration. This performance response is characteristic of cells with excessive carbonation of the electrolyte or a reduction in cell electrolyte inventory. Unfortunately progressive oxygen port plugging forced the test to be stopped at 727 hours. In order to inspect the cell without destroying evidence of plugged ports a carbonate analysis was not conducted.

A teardown inspection revealed white deposits at the hydrogen and oxygen inlets, very likely carbonates. These deposits apparently were responsible for the flow restriction during testing as the reactant exit ports were clean. In addition the deposits on the hydrogen side extended through the ERP and flow field to the PWR unit. This possibly formed a path for electrolyte transfer from the UEA to the PWR unit. Otherwise the cell was in good condition with no evidence of internal shorting or reactant crossover.

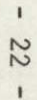
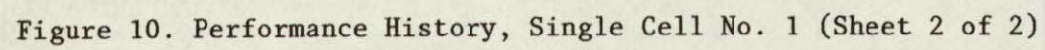


Figure 10. Performance History, Single Cell No. 1 (Sheet 1 of 2)



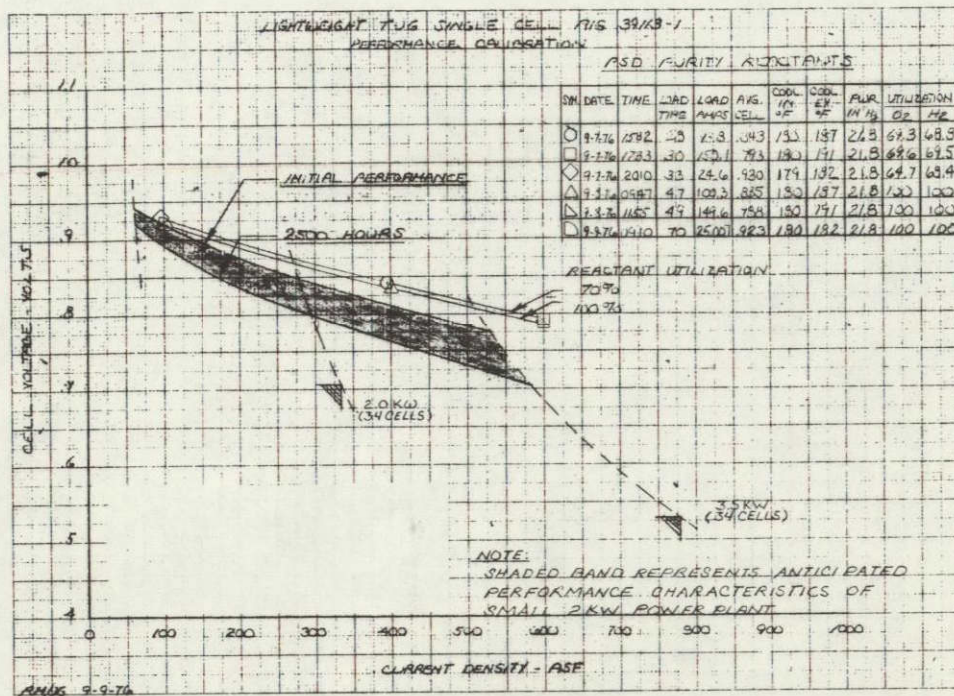


Figure 11. Performance Calibration, Single Cell No. 1

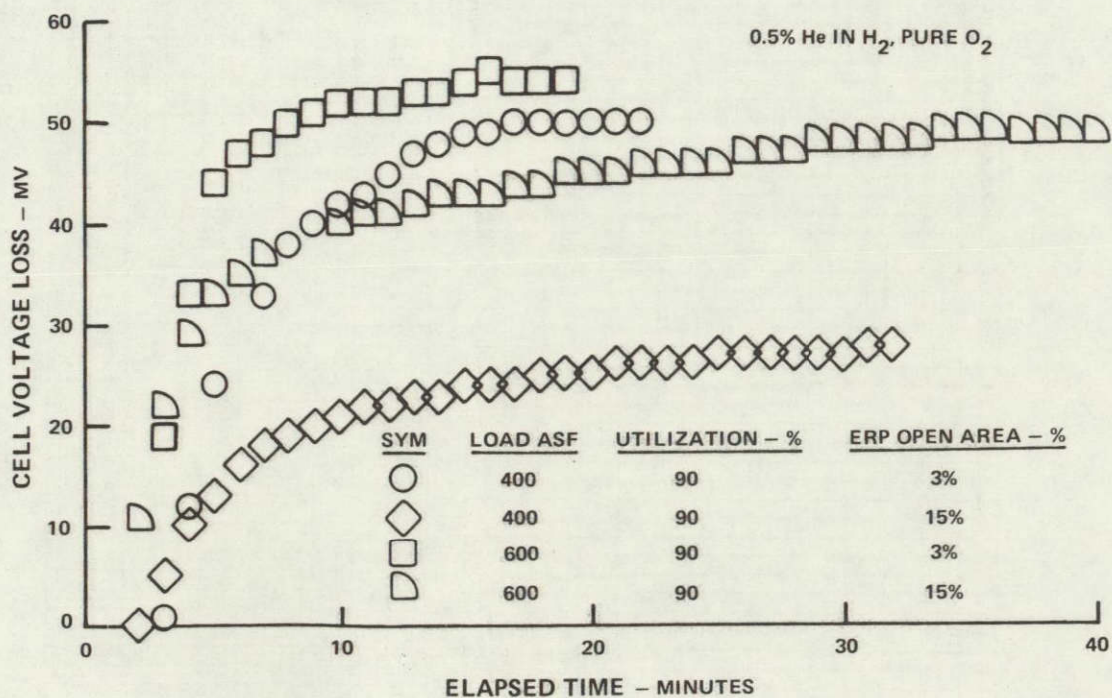


Figure 12. Performance Response to Helium on the Anode, Single Cell No. 1

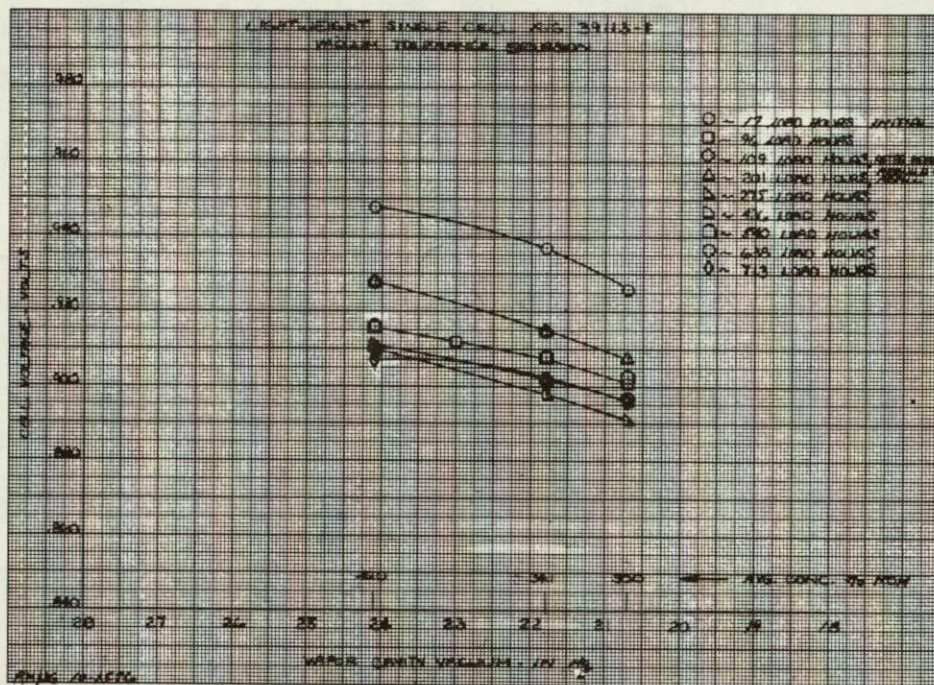


Figure 13. Electrolyte Excursion Data, Single Cell No. 1

#### Single Cell No. 2

The primary test objective of single cell No. 2 was to establish the effect of hydrogen flow field and ERP design modifications on cell performance response to helium diluted reactants. A secondary objective was to establish the performance characteristics of the  $1/4 \text{ ft}^2$  ( $232.3 \text{ cm}^2$ ) cell on pure reactants. Details of the cell construction are presented in Table II, Section IIIA. A total of 1163 hours of testing was conducted. The performance history of the cell is shown in Figure 14.

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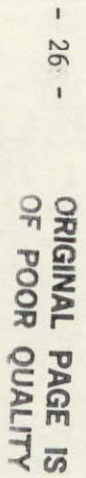
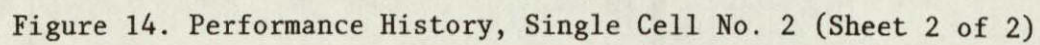


Figure 14. Performance History, Single Cell No. 2 (Sheet 1 of 2)



Initial diluent performance tests were conducted with a flow distribution bar, Figure 15, incorporated into the hydrogen flow field to eliminate any possible stagnation areas. Forcing the hydrogen to be distributed more evenly in the flow channel, any dead areas in the cell corners would be minimized. Dilute reactants tests were conducted at a current density of 400 ASF (430.6 MA/cm<sup>2</sup>), and 90% reactant utilization with 0.5% helium diluted hydrogen. The test results compared to single cell no. 1 data with the same hydrogen access area is shown on Figure 16. The flow distribution bar reduced the performance response to diluents by approximately one-half.

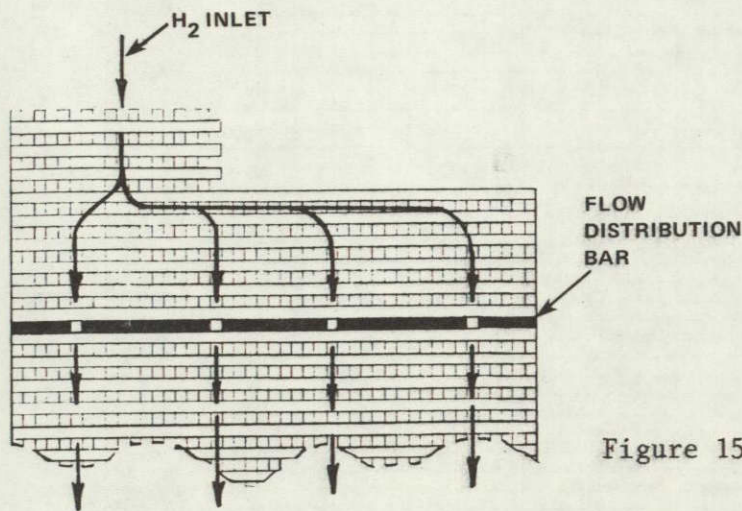


Figure 15. Hydrogen Flow Field Sketch

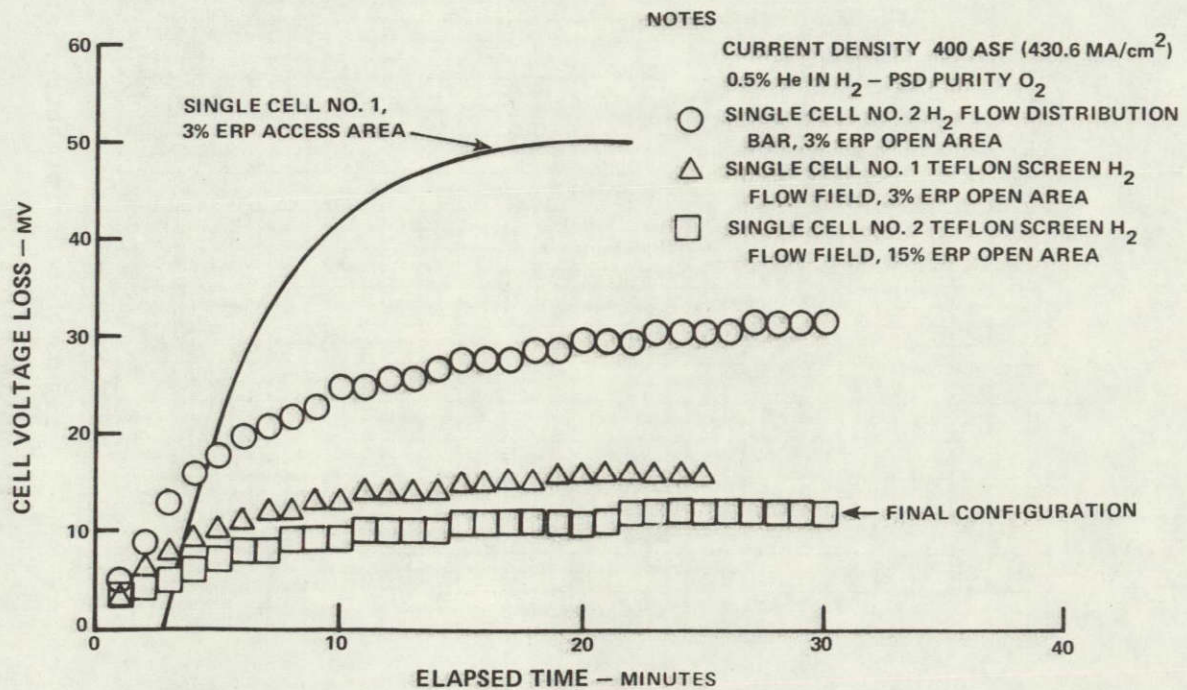


Figure 16. Performance Response to Helium on the Anode, Single Cell No. 2

Upon completion of the initial diluent testing, an endurance program on pure reactants was conducted. Electrolyte excursion tests, Figure 17, were conducted periodically. The performance response to concentration variation was normal. At 634 load hours the test was interrupted to install a Teflon screen  $H_2$  flow field for further diluent reactant tests. In the disassembly of the cell a white deposit in the active area adjacent to the inlet ports was evident.

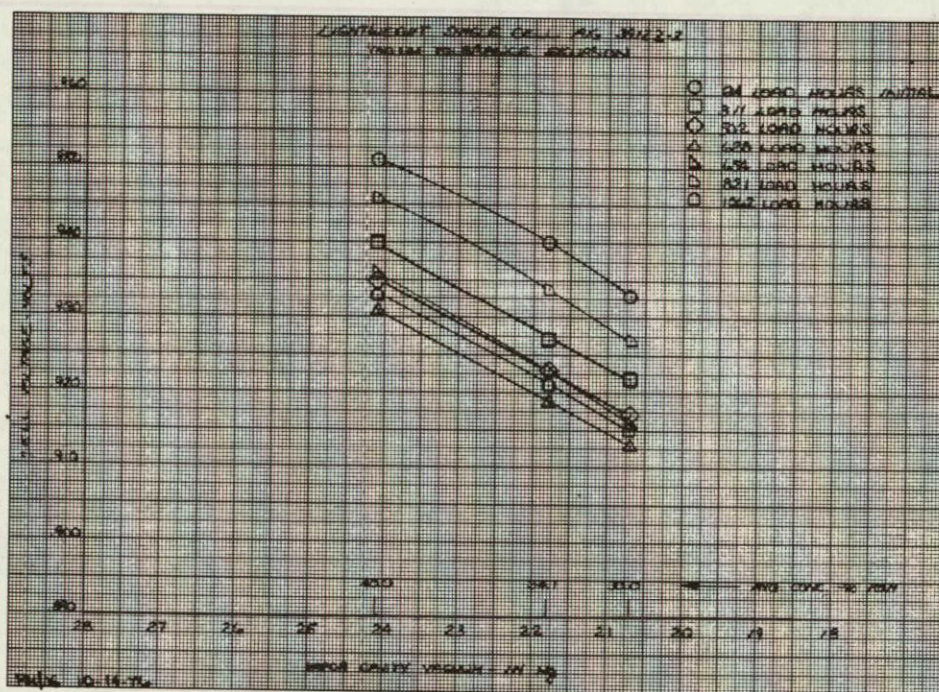


Figure 17. Electrolyte Excursion Data, Single Cell No. 2

The cell was rebuilt with a Teflon screen in place of the machined Teflon hydrogen flow field. This modification reduced coverage on the ERP and should improve hydrogen access to the anode and facilitate inert removal. Performance results on 0.5% helium diluted reactants showed a marked improvement.

The cell was rebuilt at 778 hours to install an ERP with 15% hydrogen access area. Figure 18 shows the performance reduction on 0.5% helium diluted hydrogen was only 12 mV at 400 ASF ( $430.6 \text{ MA/cm}^2$ ).

The effect of 0.1% and 0.5% helium diluted reactants on performance at current densities out to a 1000 ASF ( $1076.4 \text{ MA/cm}^2$ ) was investigated. The cell configuration during this testing contained a 15% hydrogen access area ERP, Teflon screen  $H_2$  flow field, and nickel foils at reactant inlets. Figures 18 and 19 show performance calibrations conducted with 0.5% helium and 0.1% helium diluted reactants. Both figures show that the majority of performance loss on diluents is associated with the hydrogen reactant. With 0.1% helium diluted hydrogen, the performance reduction was only 11 mV at 400 ASF ( $430.6 \text{ MA/cm}^2$ ) and 65 mV at

600 ASF ( $645.8 \text{ MA/cm}^2$ ). There was a more pronounced performance response with 0.5% helium diluted hydrogen as shown on Figure 18 with unstable voltage at 1000 ASF ( $1076.4 \text{ MA/cm}^2$ ). This problem was suspected to be the result of increasing inlet port plugging. Port plugging was suspected during an 8-hour 400 ASF ( $430.6 \text{ MA/cm}^2$ ) endurance test at 1086 load hours as it was necessary to increase the oxygen supply pressure by 2 psi ( $1.4 \text{ N/cm}^2$ ), in order to complete the test. At 1162 hours the test on single cell No. 2 was stopped for a teardown inspection.

Figure 18.  
Performance  
Calibration:  
0.5% Helium  
Diluted Reactants

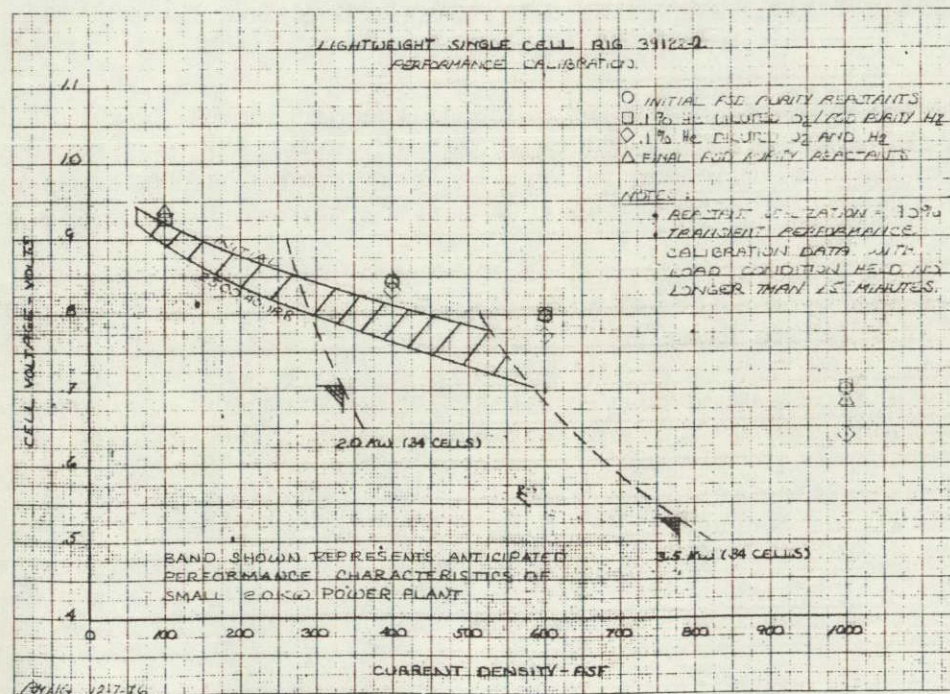
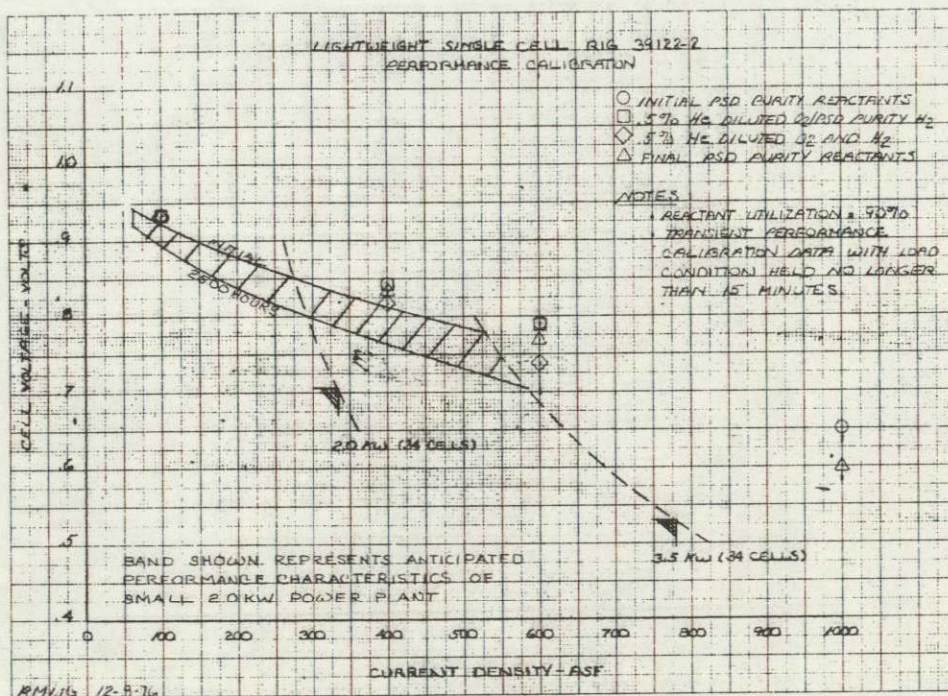


Figure 19.  
Performance  
Calibration:  
0.1% Helium  
Diluted Reactants

The teardown inspection revealed a large formation of white deposits, most likely carbonates, at the oxygen and hydrogen inlets. There was no evidence of deposits at either of the exit ports.

### Single Cell No. 3

The objective of the test was to establish the effect of hydrogen flow field and ERP modifications on performance response to helium diluted reactants. Details of the cell construction are presented in Table II, Section IIIA. A total of 131 hours of operation at a 180°F (82.2°C) cell temperature, a current density of 100 ASF (107.6 MA/cm<sup>2</sup>), and 16 psia (11.03 N/cm<sup>2</sup>) reactant pressure was completed. Performance evaluation of the cell modifications was stopped because of a coolant to oxygen leak. The performance history of the cell is shown in Figure 20.

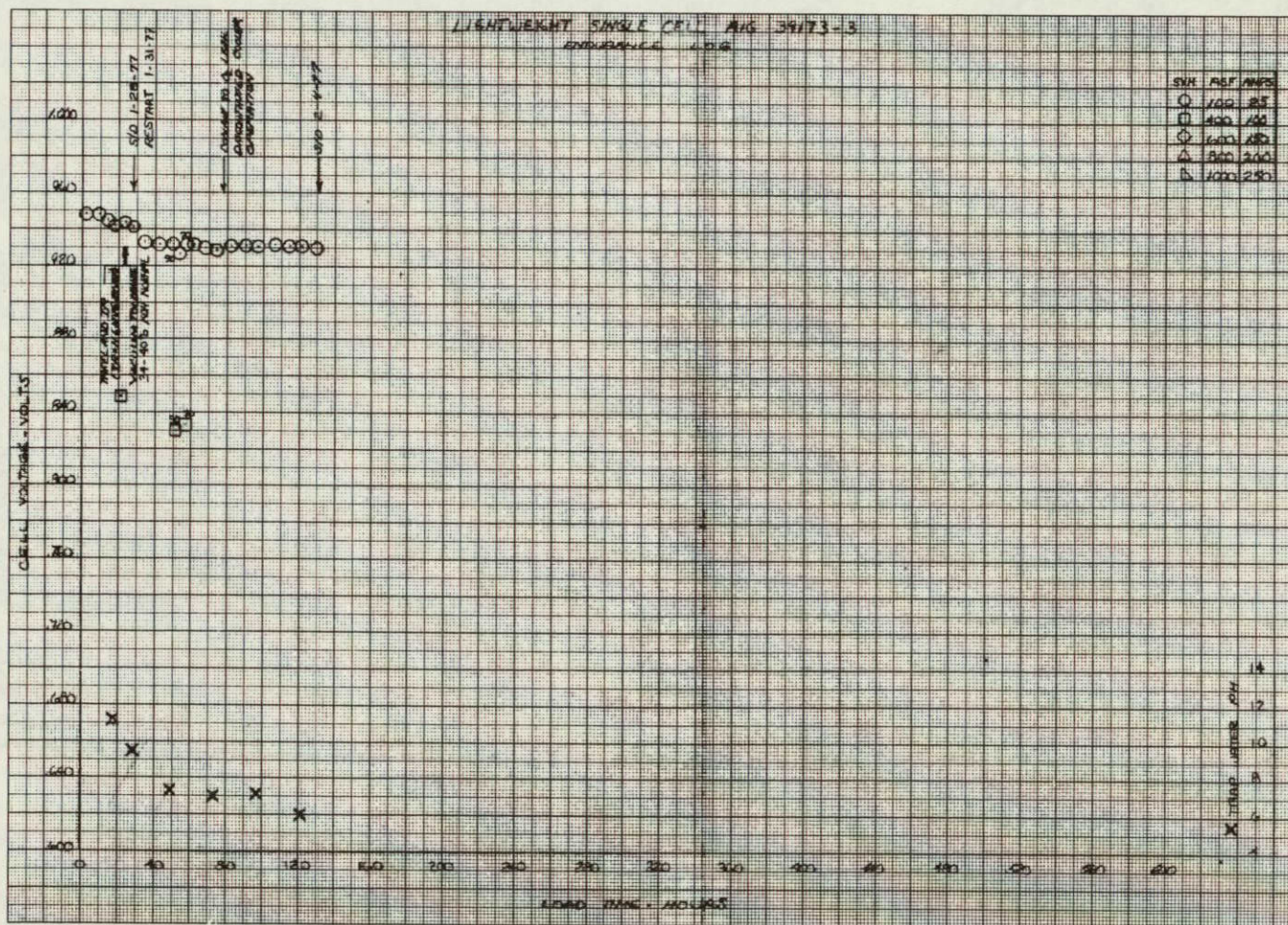


Figure 20. Performance History, Single Cell No. 3

The initial performance of the cell as shown in Figure 21 exceeded the design requirements of the 2.0 kW powerplant.

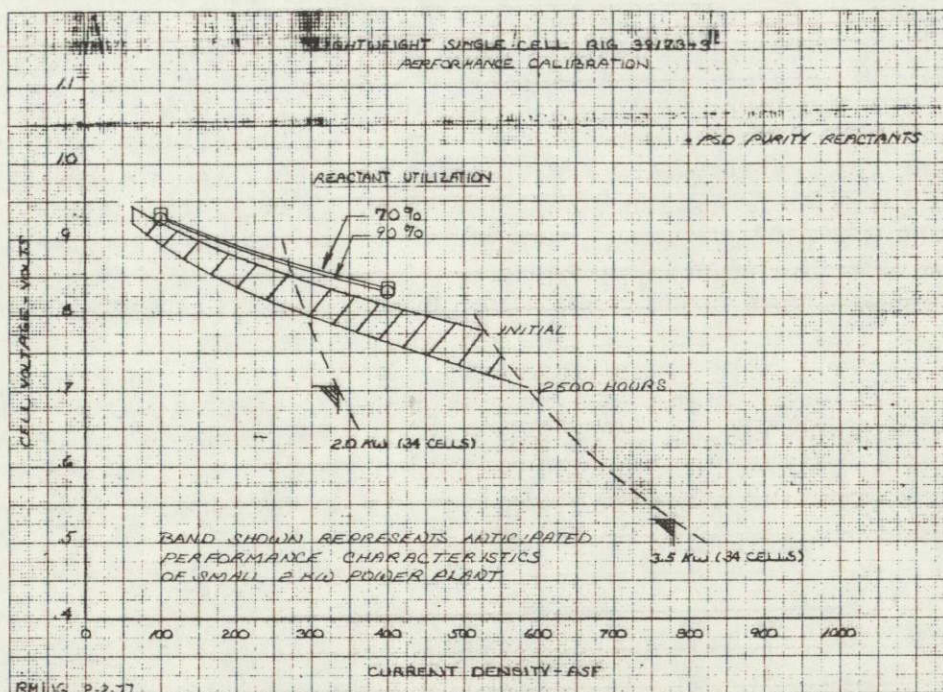


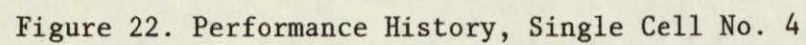
Figure 21. Performance Calibration, Single Cell No. 3

The cooler was no longer utilized after finding coolant in the oxygen vent trap at 88 hours. Subsequently the cell performance history remained exceedingly stable until the test was stopped at 131 hours.

A teardown inspection of the cell cooler located a coolant leak from the coolant manifold at the oxygen-coolant bond line. The passive water removal assembly was removed successfully undamaged and utilized in Single Cell No. 4.

#### Single Cell No. 4

This cell was fabricated identical to the final configuration of Single Cell No. 2. A description of the cell can be found in Table II, Section IIIA. The test objective was to determine the effect of helium diluted reactants on cell performance. A total of 356 hours of performance evaluation testing was completed. The performance history of the cell is presented in Figure 22.



The performance response of the cell to variations in operating electrolyte concentration was investigated periodically during the test. The results of the electrolyte excursion testing is presented in Figure 23. As shown the performance response to electrolyte concentration variation at 351 load hours was nearly unchanged from the initial test results. The slight performance droop at 34% wt. KOH was caused by a change in barometric pressure. Test results from oxygen Tafel diagnostics obtained during the test are shown in Figure 24.

Initial evaluation tests with 0.5% helium diluted reactants exhibited a performance response as a function of load consistent with single cells No's. 1 and 2. However test results with 0.1% helium diluted reactants showed a markedly reduced performance effect over previous experience. The reason was subsequently traced to the use of a 0.1% helium diluted hydrogen bottle from a different source. An analysis of the gas bottles used initially showed high levels of CO and CO<sub>2</sub> in the hydrogen, and high levels of CO<sub>2</sub> in the oxygen. These results would account for the large performance response to helium diluted reactants, excessive voltage loss with time, and port plugging experienced initially on this cell and on Single Cell No's. 1 and 2. A carbonate analysis of cell electrolyte at 187 load hours showed a 51% conversion to carbonates confirming the impact of CO and CO<sub>2</sub> contaminants in the diluted reactant supply on performance.

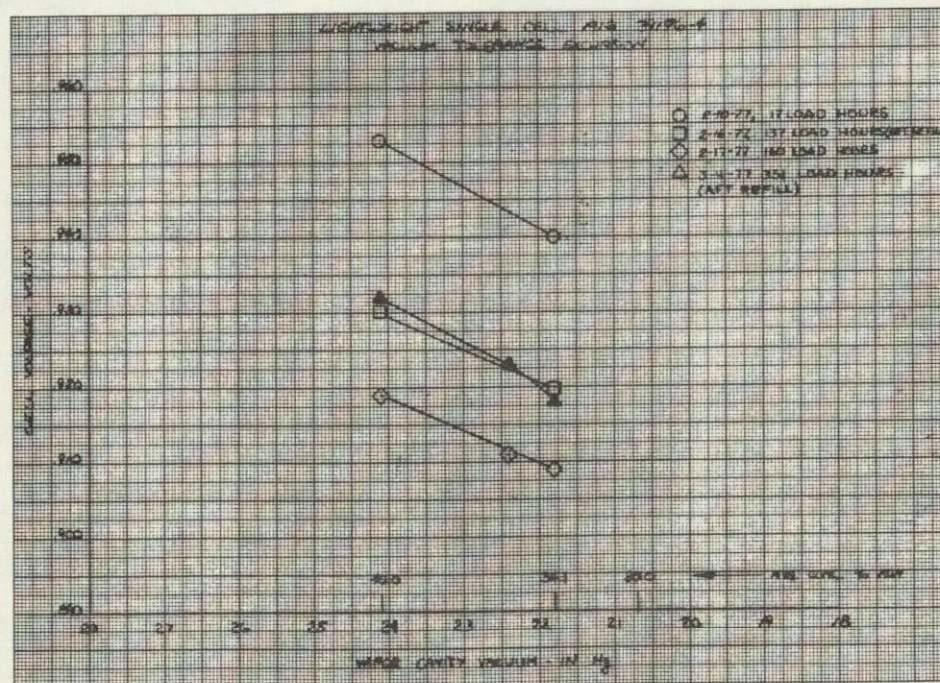


Figure 23. Electrolyte Excursion Data, Single Cell No. 4

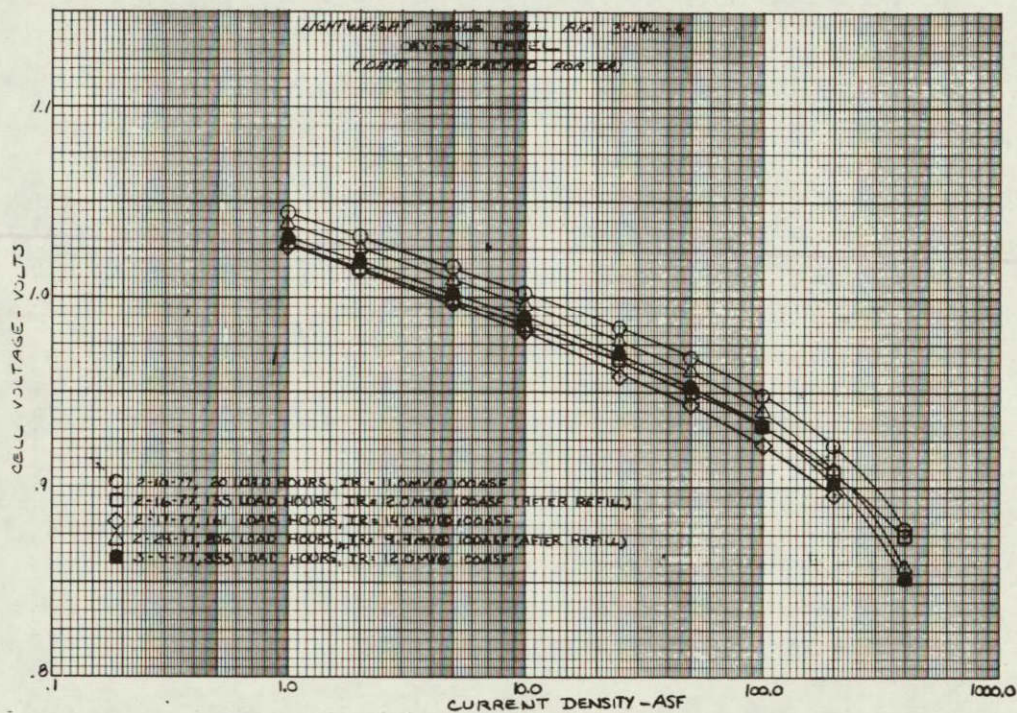


Figure 24. Oxygen Tafel Diagnostic Data, Single Cell No. 4

The results of performance calibrations at reactant utilizations from 70 percent to 100 percent on pure reactants are shown in Figure 25. The effect of utilization on cell performance was very small and the performance level at each utilization exceeded the design performance criteria used to establish the small 2.0 kW powerplant design.

Following an electrolyte refill, evaluation of the performance response to helium diluted reactants was continued with uncontaminated reactant supplies. The test results indicated a small performance reduction on 0.5% He diluted reactants consistent with predictions. At low current densities, 100 ASF (107.6 MA/cm<sup>2</sup>), and below, the effect on performance was negligible. The performance response to 0.5% and 0.1% helium diluted reactants as a function of reactant utilization is presented in Figure 26. This data indicates that the effect of utilization in the range of 70 to 90 percent to be insignificant. In addition the small performance response affirms that there was no inert build up either in the corners or between the anode and ERP.

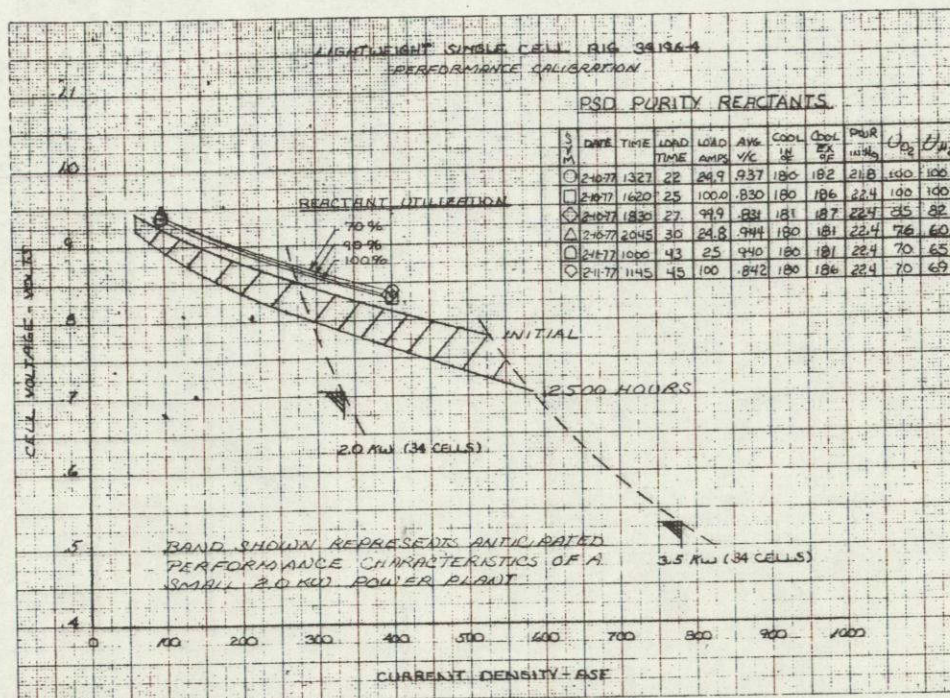


Figure 25. Performance Calibration, Single Cell No. 4

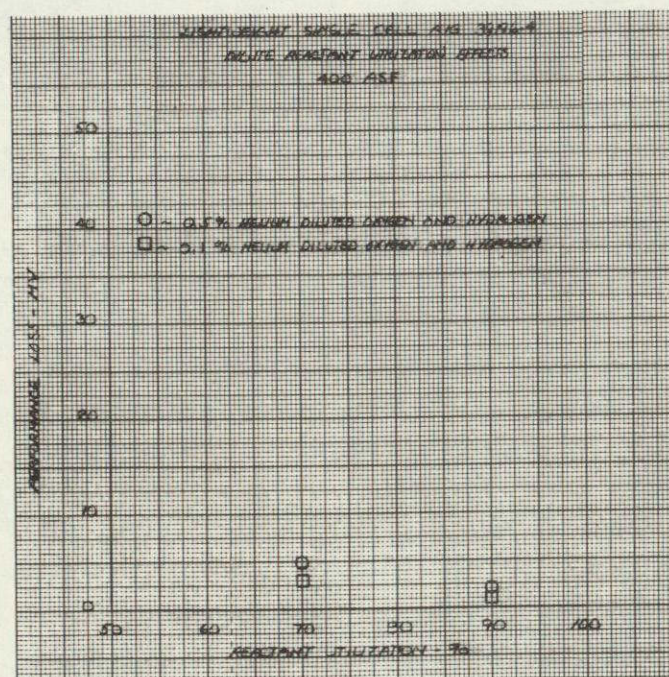


Figure 26. Effect of Reactant Utilization, and Diluents on Performance

An intermittent purge program was conducted with 0.5 percent and 0.1 percent diluted reactant at 100 ASF ( $107.6 \text{ MA/cm}^2$ ) and 400 ASF ( $430.6 \text{ MA/cm}^2$ ). These tests were conducted on the individual reactants in order to identify the performance response on each reactant. The intermittent purge response data for diluted hydrogen is shown on Figure 27 and for diluted oxygen on Figure 28. The data is shown as a performance reduction as a function of elapsed amp-hours of operation since reactant purge. The data was obtained by alternately setting 100 ASF ( $107.6 \text{ MA/cm}^2$ ) and 400 ASF ( $430.6 \text{ MA/cm}^2$ ) loads for various time intervals, monitoring cell voltage until a 100 mV at 100 ASF ( $107.6 \text{ MA/cm}^2$ ) performance loss had occurred. The data scatter evident at 400 ASF ( $430.6 \text{ MA/cm}^2$ ) on 0.1 percent helium diluted reactants is the result of test stand reactant pressure instabilities. Utilizing the data obtained during the intermittent purge investigation, a cell operating on 0.1% helium diluted reactants without reactant purging at 100 ASF ( $107.6 \text{ MA/cm}^2$ ) would experience about 40 mV performance loss in 20 amp-hours of operation.

Upon completion of the intermittent purge investigation the performance of the cell at 1000 ASF ( $1076.4 \text{ MA/cm}^2$ ) was determined. The data obtained is shown on the cell performance history, Figure 22, at 330 load hours. A total of 140 minutes of operation at 1000 ASF ( $1076.4 \text{ MA/cm}^2$ ) was completed. The effect of helium diluents in the reactants on performance at 1000 ASF ( $1076.4 \text{ MA/cm}^2$ ) was relatively small, the performance reduction with 0.1 percent helium diluted reactants was approximately 5 mV. At a 0.5% helium diluent level the performance degradation was approximately 20 mV at 1000 ASF ( $1076.4 \text{ MA/cm}^2$ ).

Following completion of the 1000 ASF ( $1076.4 \text{ MA/cm}^2$ ) operation further testing of the cell was discontinued. The cell was subsequently delivered to NASA-LeRC as the first of the two deliveries scheduled during this program.

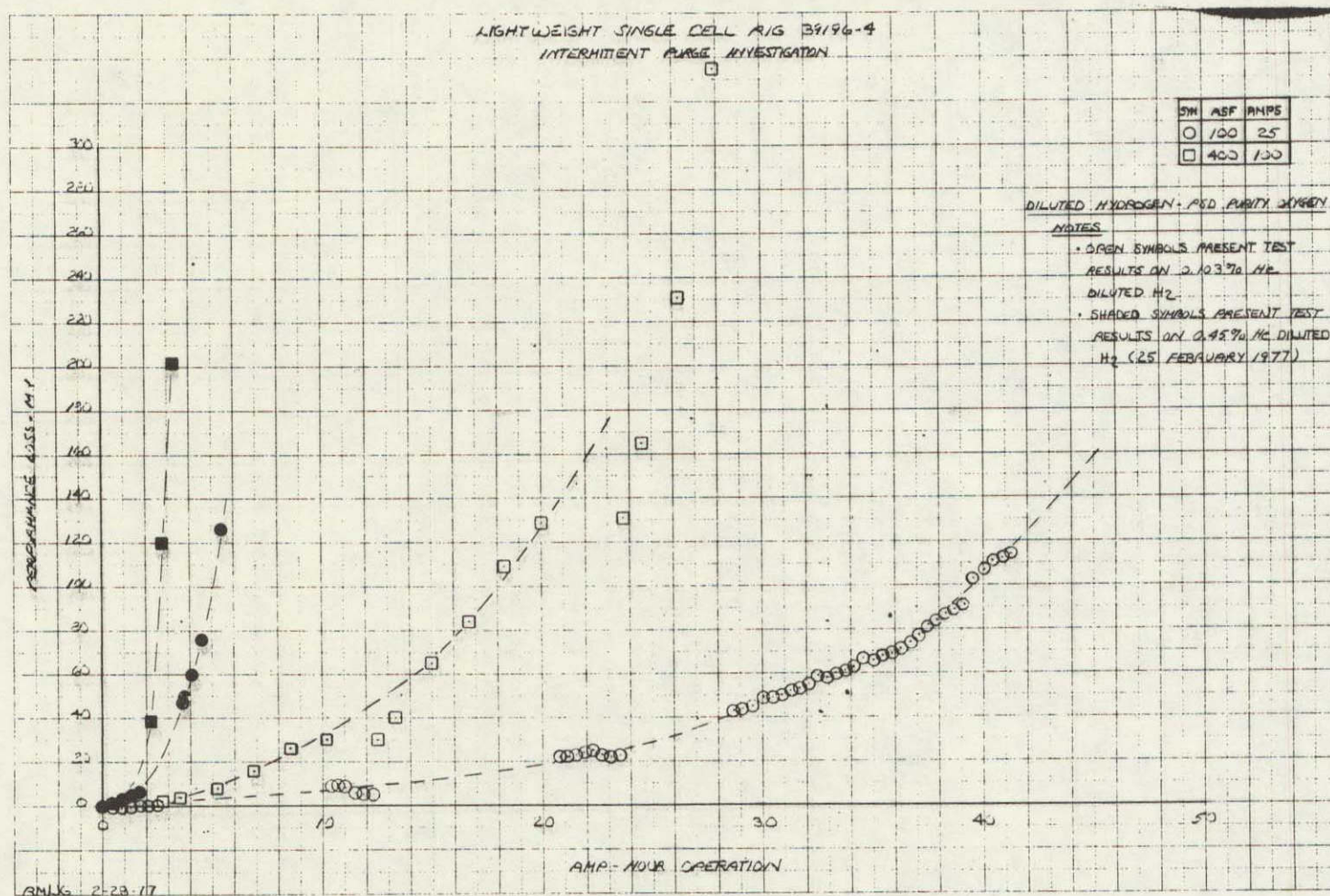


Figure 27. Intermittent Purge Investigation, Hydrogen, Single Cell No. 4

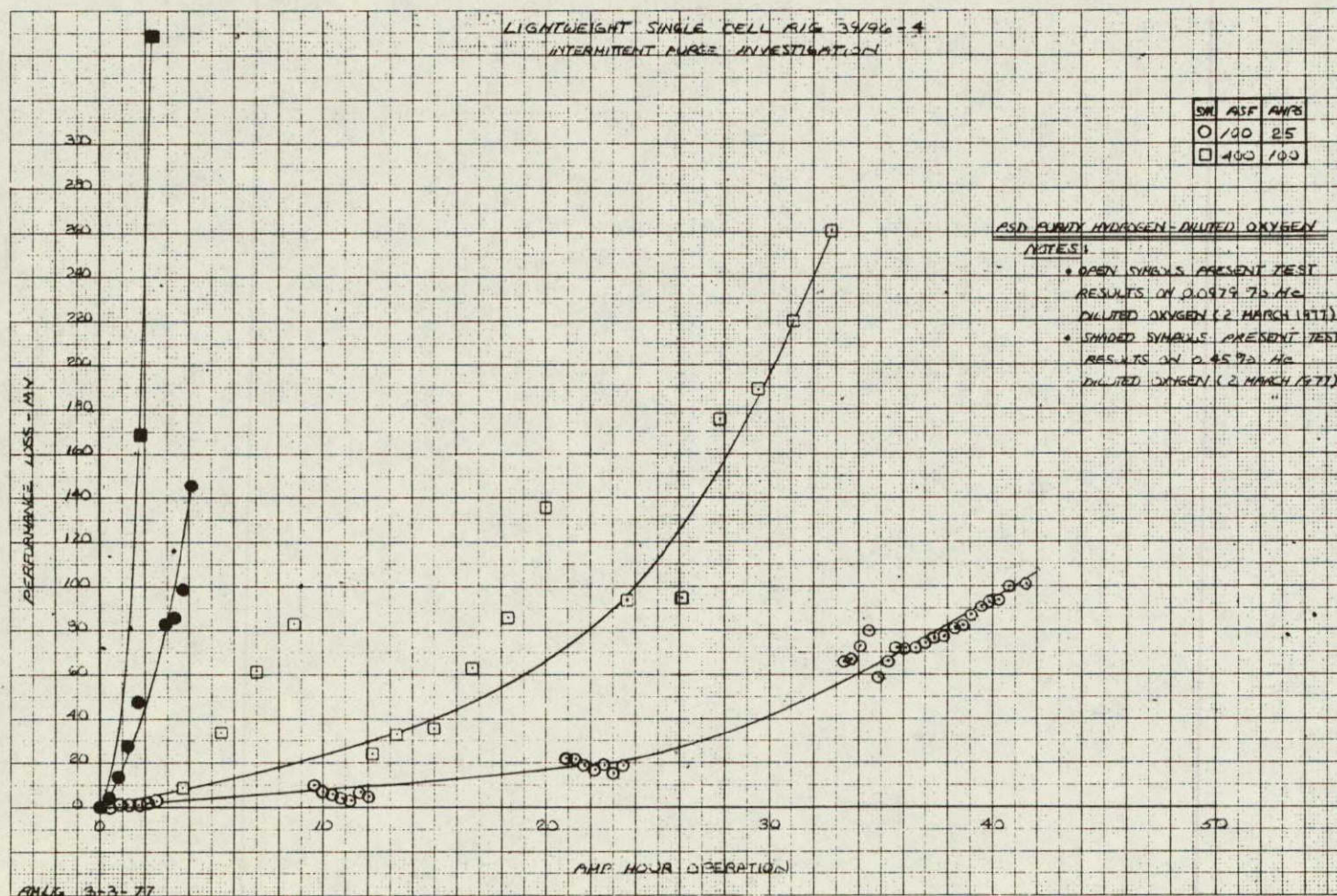


Figure 28. Intermittent Purge Investigation, Oxygen, Single Cell No. 4

## Single Cell No. 5

This cell was fabricated to the final  $1/4 \text{ ft}^2$  ( $232.3 \text{ cm}^2$ ) cell configuration described in Section IIIA. The objective of the test was to demonstrate the endurance capability of the final  $1/4 \text{ ft}^2$  ( $232.3 \text{ cm}^2$ ) configuration. A total of 1242 hours of endurance operation was completed during the contract with an additional 3747 hours accumulated during a no-cost contract extension for a total of 5039 hours of operation. The cell was subjected to a weekly load profile through 4000 hours of operation. The complete performance history of the cell is presented in Figure 29.

The results of periodic performance calibrations are shown on Figure 30. The anticipated performance characteristics of the small 2 kW powerplant is shown for comparison purposes. As shown the performance of Cell No. 5 exceeded powerplant design voltage requirements out to 3712 hours.

Figure 31 presents oxygen Tafel test data and cell internal resistance (IR) measurement obtained during the endurance test. The performance change with time was nearly equally divided between a decrease in cathode activation level and increased in diffusion loss.

Test results from periodic electrolyte excursion tests are shown on Figure 32. The performance response to increasing the electrolyte concentration from the nominal 34% wt. KOH to 40.0% wt. KOH was normal through 2263 hours of testing. This represents a 7.5 times increase in endurance capability over cells with wettable hydrogen flow fields. As discussed in the previous program: (ref. 1) cells with wettable  $\text{H}_2$  flow fields limited cell life to around 300 hours because of apparent electrolyte transfer between cell and passive water removal unit. Electrolyte excursion test results strongly indicate that the Teflon flow field used in the  $1/4 \text{ ft}^2$  ( $232.3 \text{ cm}^2$ ) cell configuration has retarded cell electrolyte loss. The droop in performance at 40% wt KOH shown on Figure 32 at 3066 hours continuing through the remainder of the test may have resulted from carbonation of the electrolyte or a reduction in cell electrolyte inventory. A carbonate analysis conducted at 5039 load hours indicated 20.5% conversion of the KOH to  $\text{K}_2\text{CO}_3$  which is consistent with past NASA-LeRC experience.

## Single Cell NO. 6

Single Cell No. 6 was of the same design and construction as Single Cell No's. 4 and 5. A complete description of the cell can be found in Section IIIA. This cell was the second one delivered to NASA-LeRC for performance testing and evaluation. A short performance evaluation test was conducted at PSD prior to delivery. A total of 53 load hours was accumulated during the checkout. The performance history of the cell is shown in Figure 33.

The results of a performance calibration shown in Figure 34 indicated a performance level consistent with the initial performance of the small lightweight powerplant design. The performance response to variation in electrolyte concentration shown in Figure 35 was normal. Oxygen Tafel Data, Figure 36, was obtained to provide a baseline for performance evaluation.

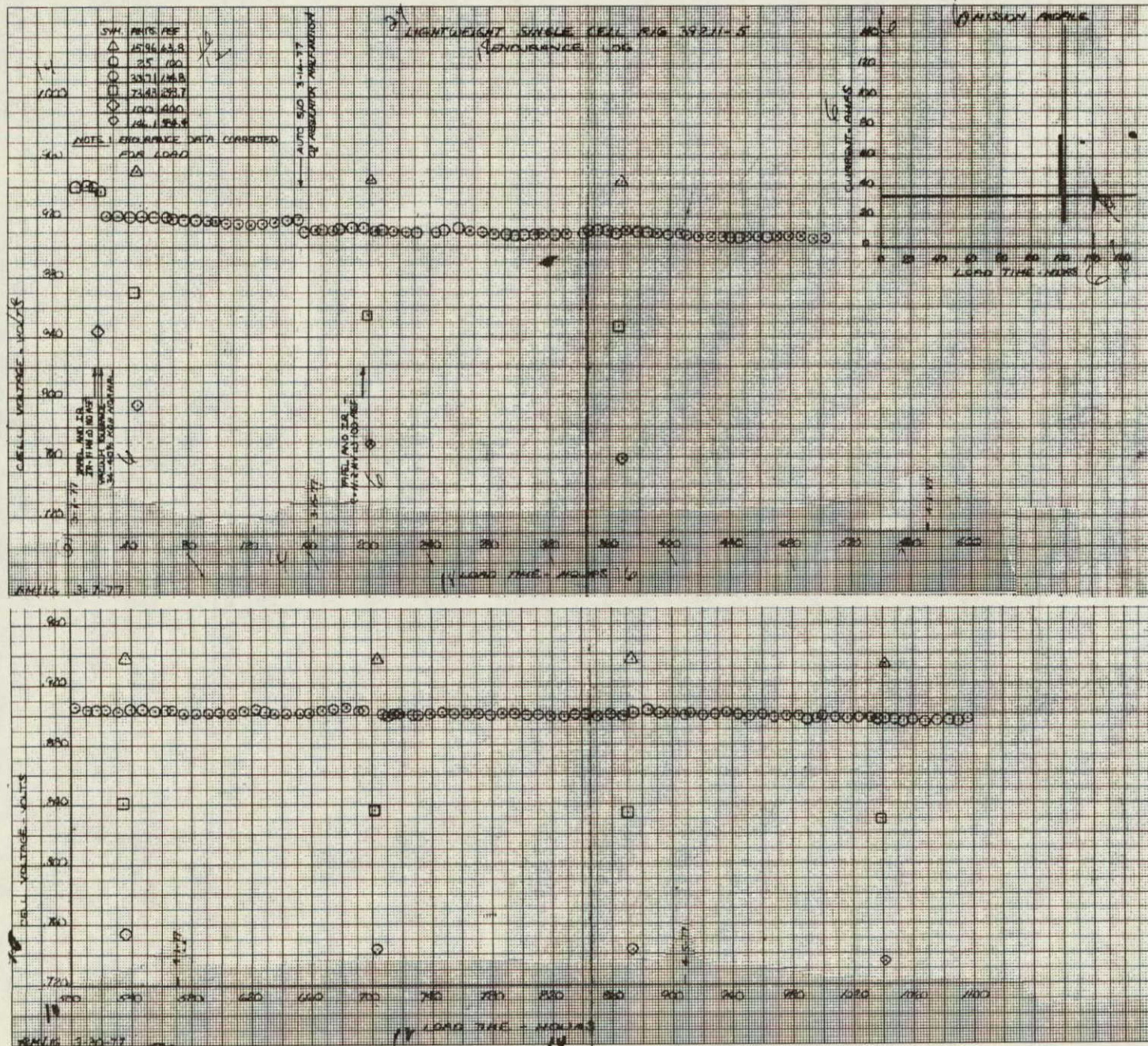


Figure 29. Performance History, Single Cell No. 5 (Sheet 1 of 8)



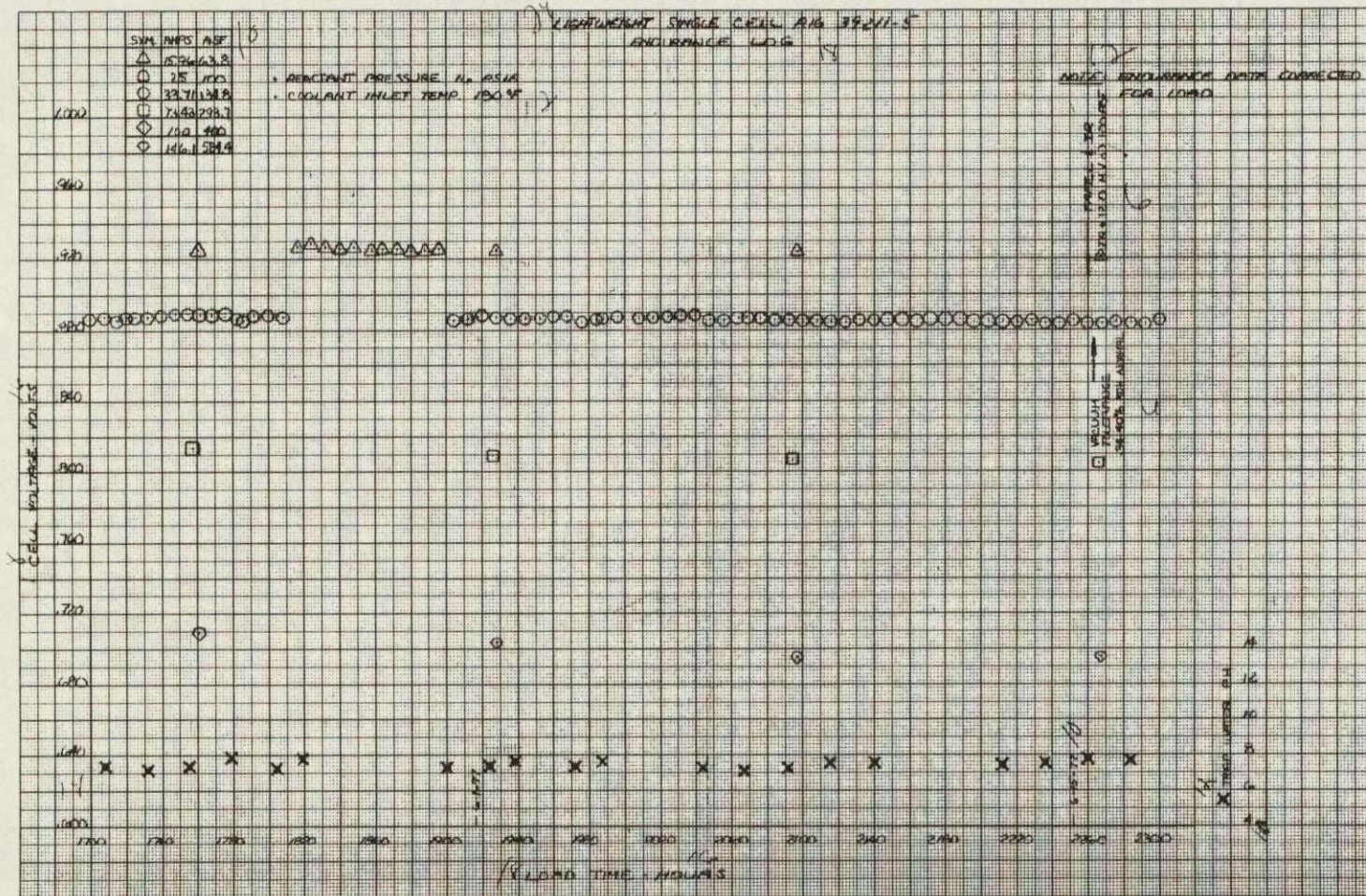


Figure 29. Performance History, Single Cell No. 5 (Sheet 3 of 8)



LOAD TIME - HOURS



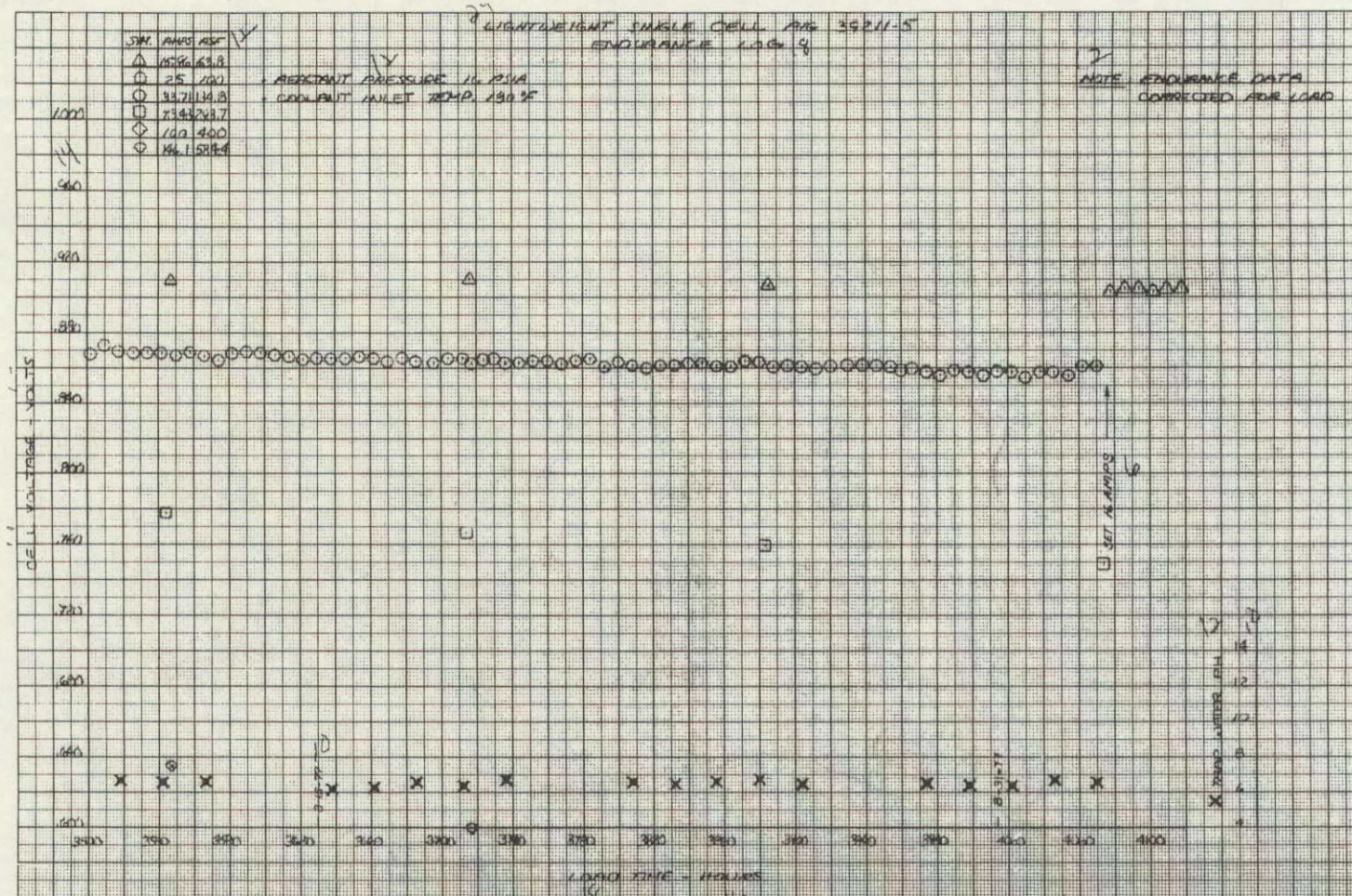


Figure 29. Performance History, Single Cell No. 5 (Sheet 6 of 8)



Figure 29. Performance History, Single Cell No. 5 (Sheet 7 of 8)

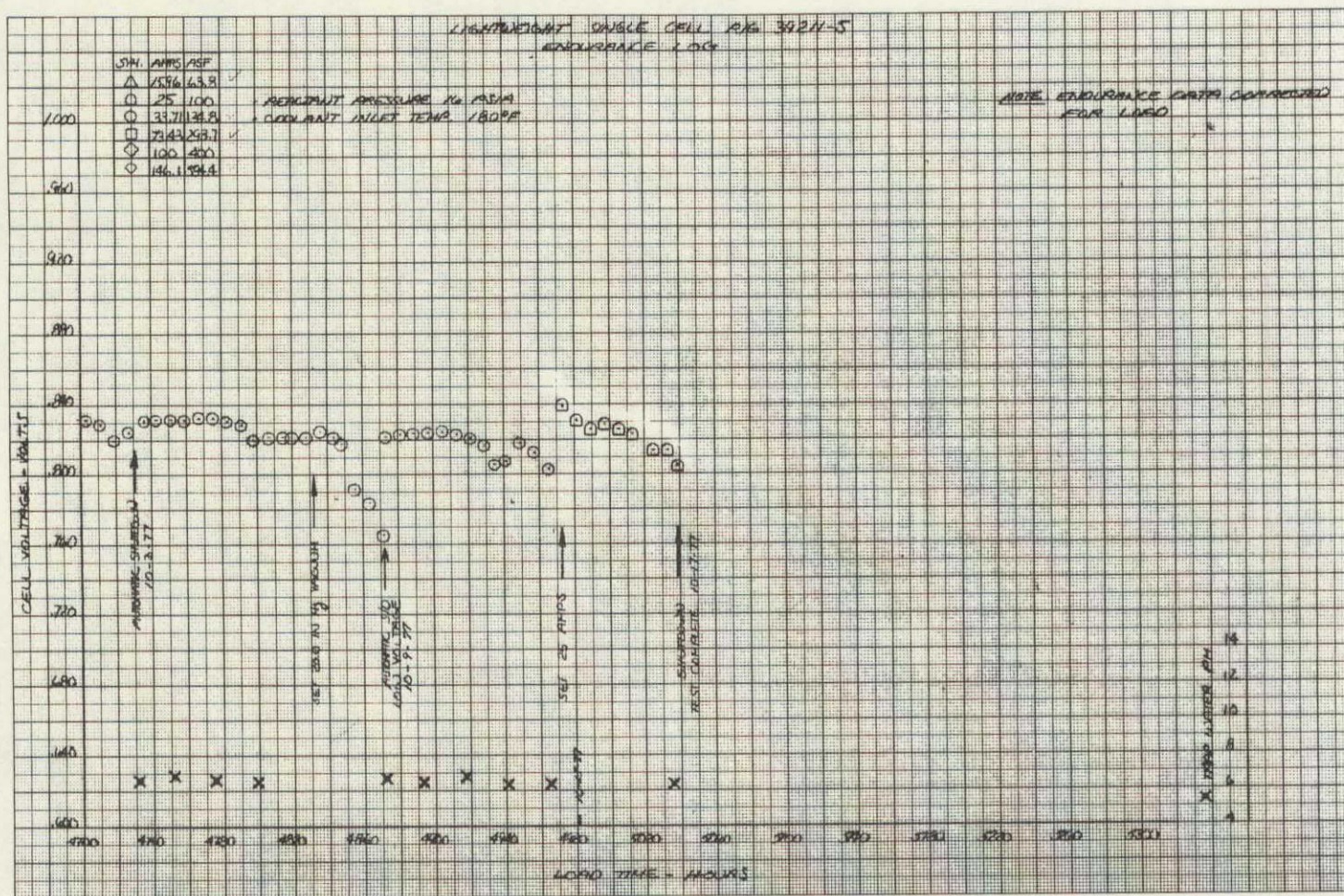


Figure 29. Performance History, Single Cell No. 5 (Sheet 8 of 8)

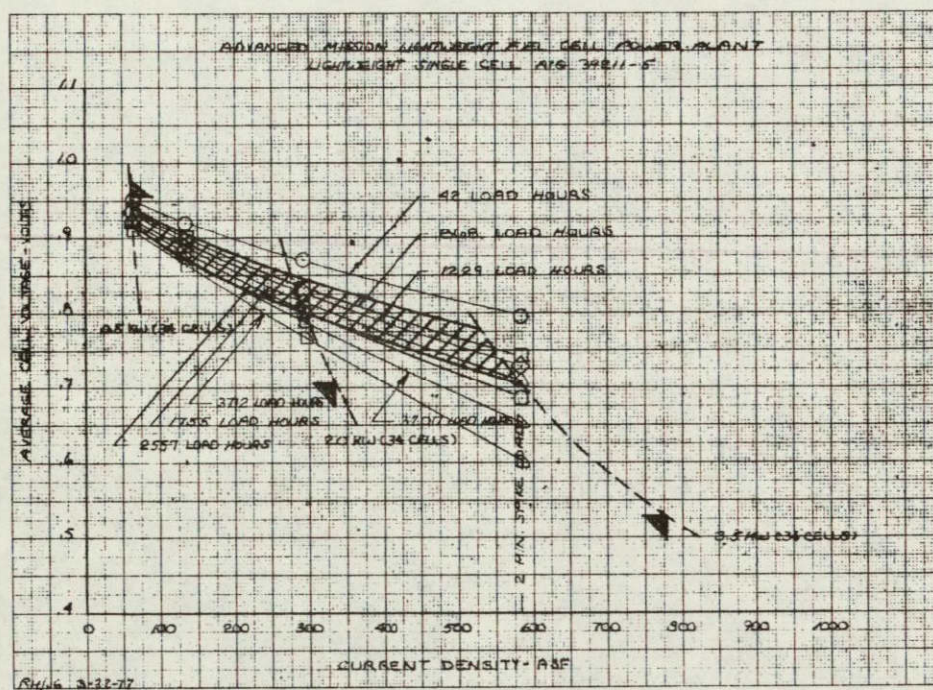


Figure 30. Performance Calibration, Single Cell No. 5

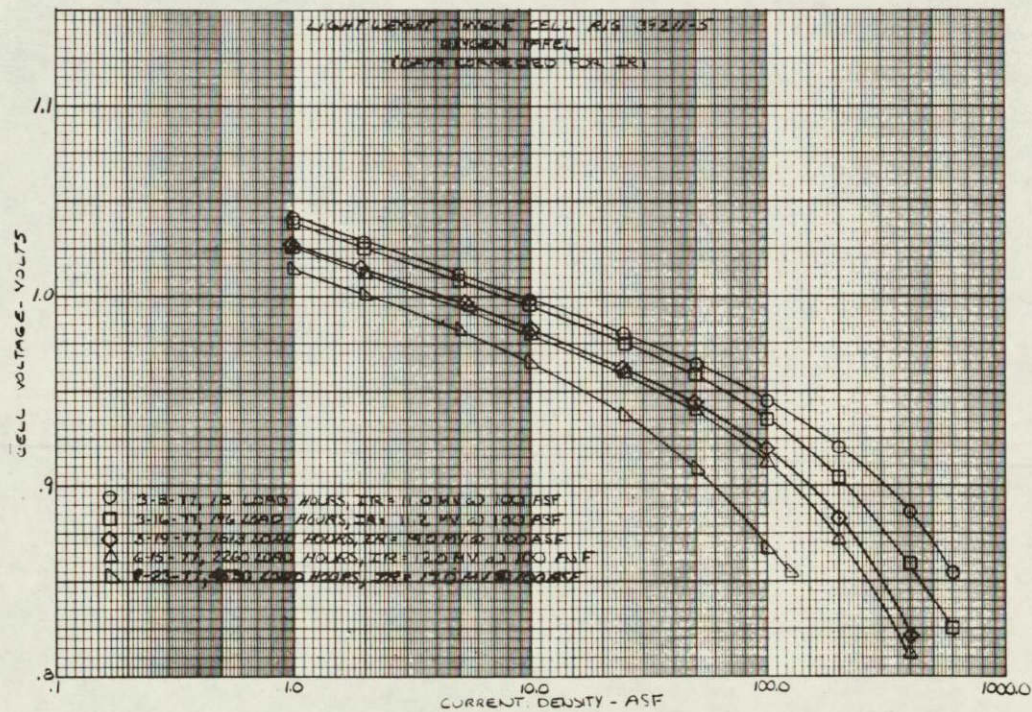


Figure 31. Oxygen Tafel Diagnostic Data, Single Cell No. 5

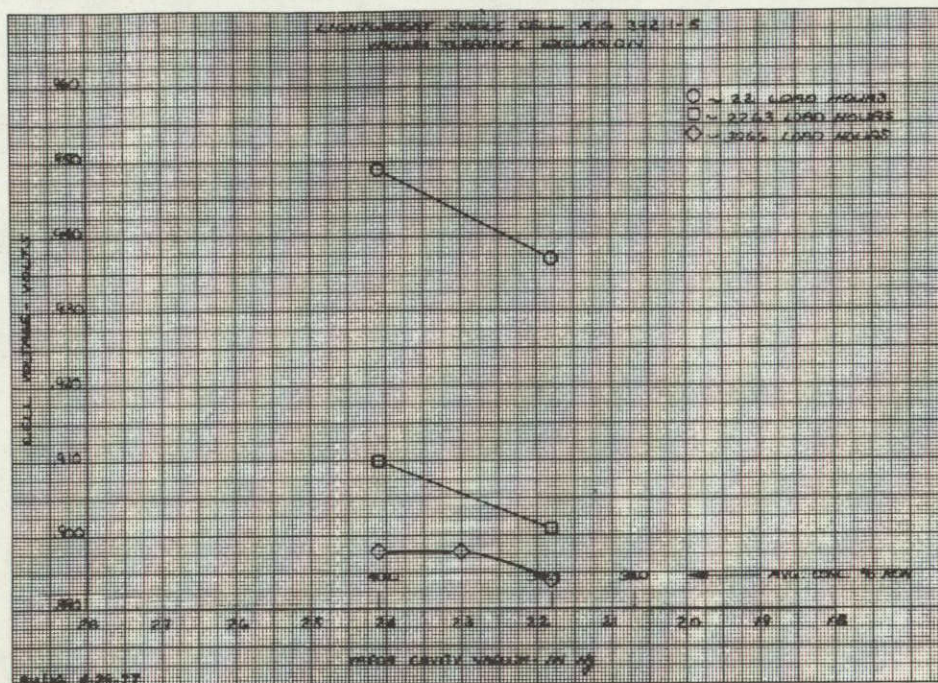


Figure 32. Electrolyte Excursion Data, Single Cell No. 5

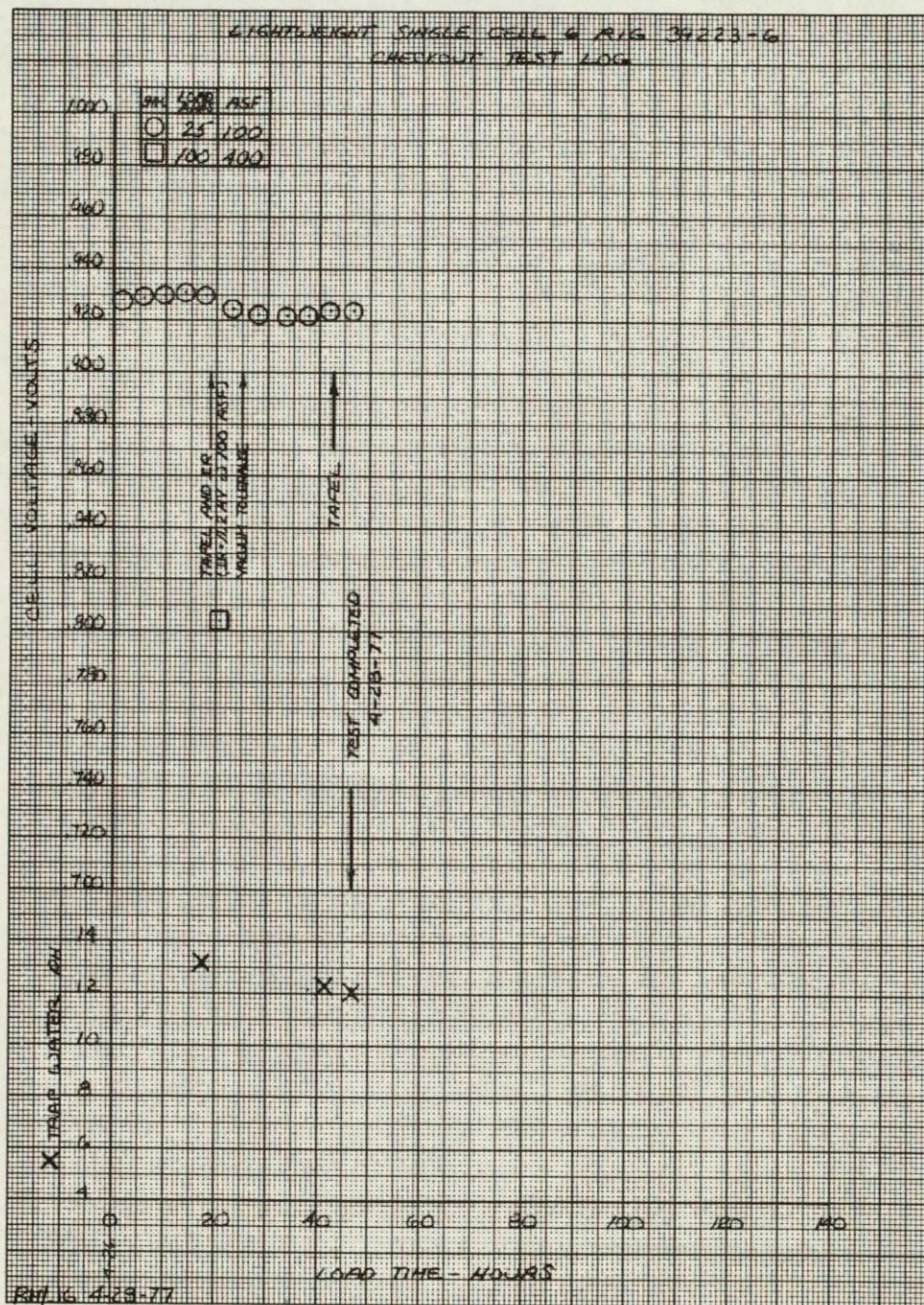


Figure 33. Performance Checkout Test History, Single Cell No. 6

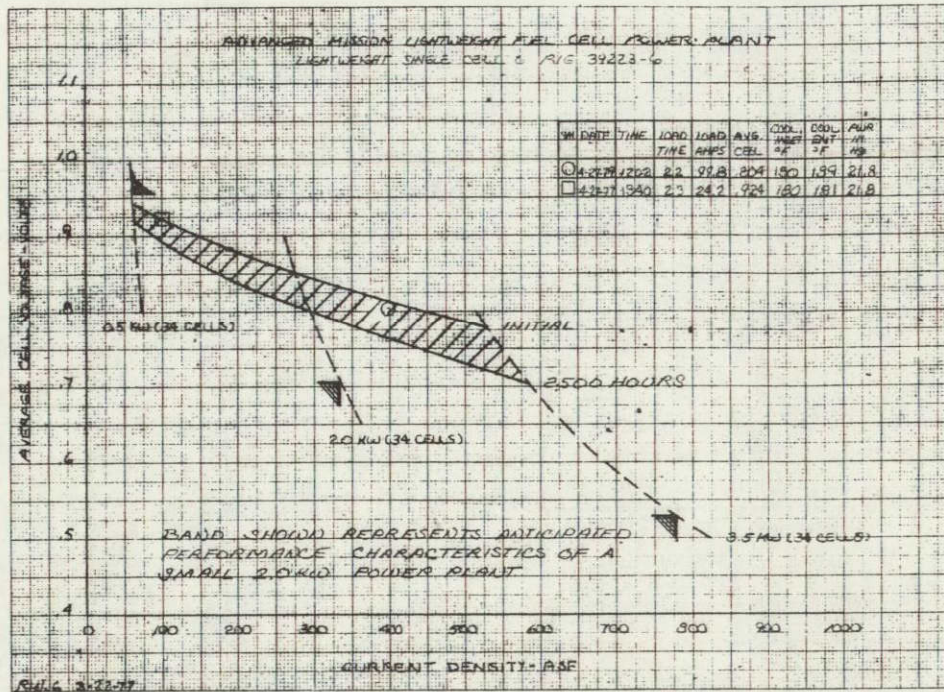


Figure 34. Performance Calibration, Single Cell No. 6

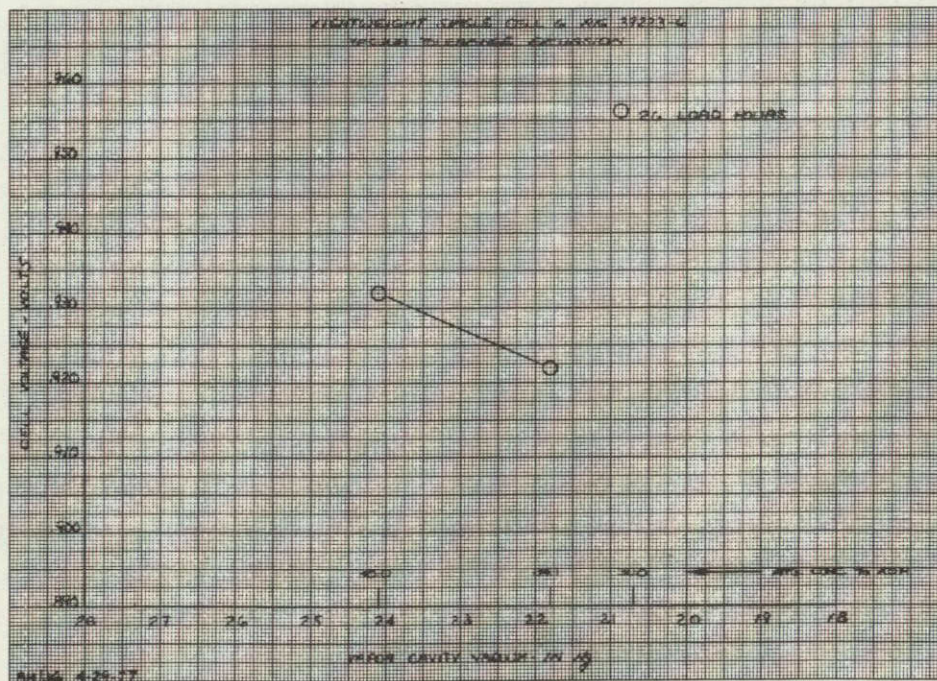


Figure 35. Electrolyte Excursion Data, Single Cell No. 6

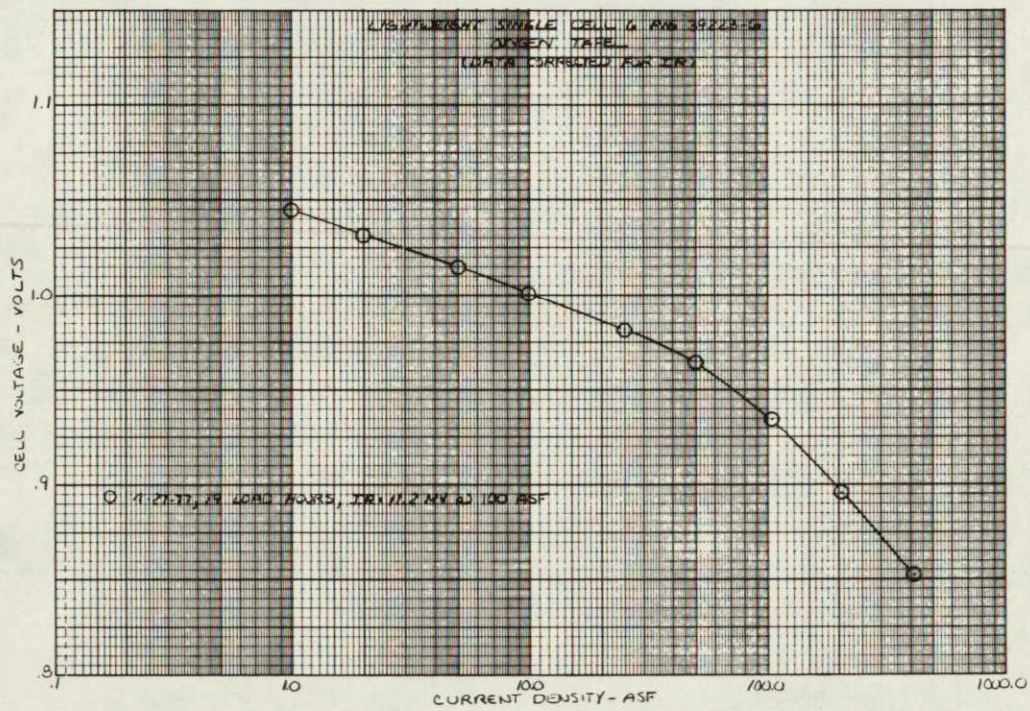


Figure 36. Oxygen Tafel Diagnostic Data, Single Cell No. 6

APPENDIX B

DETAILS OF TEFLON SCREEN FLOW FIELD CONFIRMATION TESTS

## APPENDIX B

DETAILS OF TEFLON SCREEN FLOW FIELD  
CONFIRMATION TESTS

## Single Cell No. 46

Single Cell No. 46 was fabricated to the  $1/10 \text{ ft}^2$  ( $92.9 \text{ cm}^2$ ) cell configuration described in Section IIIB. The objective of the test was to continue the endurance evaluation of the Teflon screen hydrogen flow field. During the previous contract, NAS 3-19778 (ref. 1) 1850 hours of testing were completed. In the current program an additional 363 hours were acquired for a total of 2213 hours of operation. The performance history of the cell during the current program is presented on Figure 37.

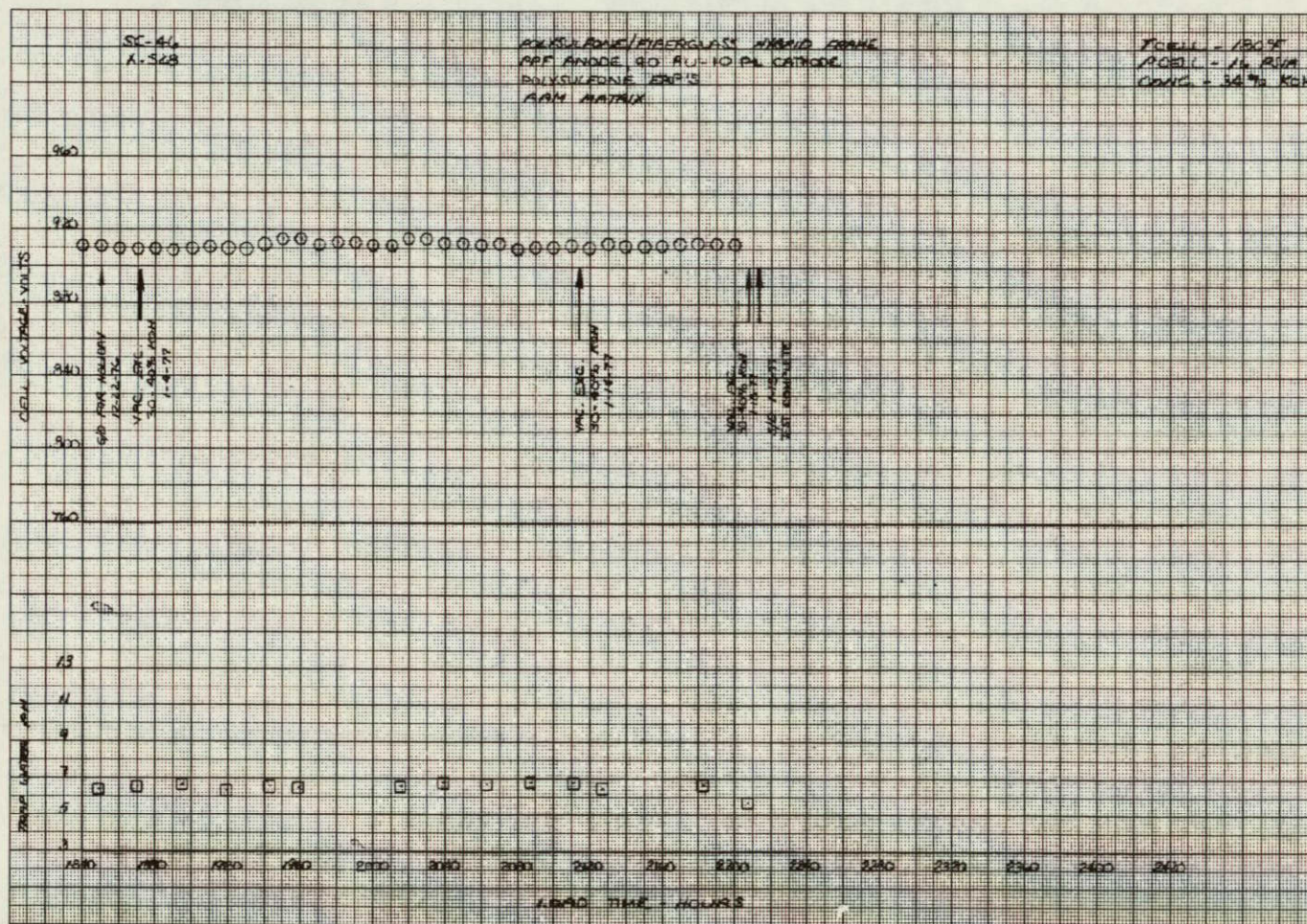


Figure 37. Performance History, Single Cell No. 46

The performance response to variation in electrolyte concentration with time is shown in Figure 38. The cell had been subjected to an electrolyte refill at 1491 hours (ref. 1) to assure adequate electrolyte before starting evaluation of the Teflon screen flow field. A total of 717 hours of operation was completed since that refill without there being any evidence of a droop in performance upon increasing the concentration from 34% to 40% wt. KOH. This represents an increase of more than twice the endurance capability over cells with wettable hydrogen flow fields. Electrolyte excursion test results indicate that the Teflon screen flow field retarded apparent transfer of electrolyte from the cell to passive water removal unit.

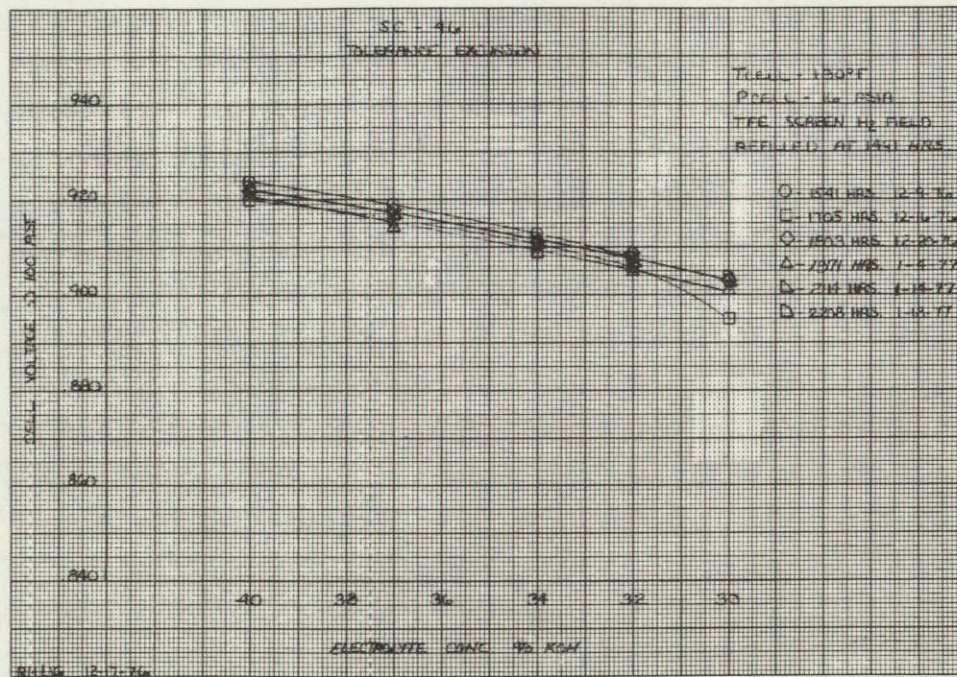


Figure 38. Electrolyte Excursion Data, Single Cell No. 46

#### Two-Cell Plaque No. 4

Two-Cell plaque No. 4 (TCP-4) was constructed to the configuration identified in Section IIIC. A photograph of two-cell plaque components is shown in Figure 39. Test results of the previous two-cell plaques are reported in reference 1. The test objective of TCP-4 was to demonstrate that a Teflon screen hydrogen flow field would extend the operating life of the plaque design by retarding cell to passive water removal unit electrolyte transfer. This problem had limited the operating life of previous plaques to around 300 hours.

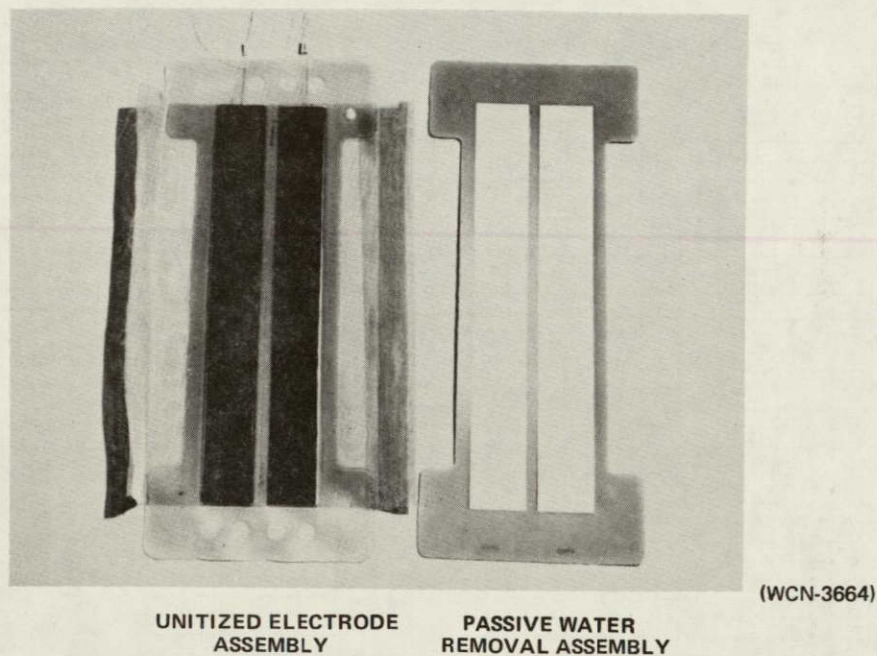
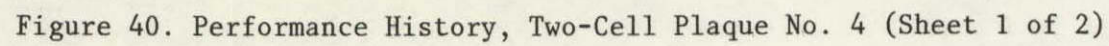


Figure 39. Two-Cell Plaque Components

A total of 859 hours of endurance testing was completed. The performance history of TCP-4 is shown on Figure 40.

The performance response of the cells in the plaque to variation in electrolyte concentration is shown in Figure 41. The slight droop in performance at 740 hours upon setting a 40% wt. KOH concentration could be caused by excessive carbonates within the electrolyte or a reduction in cell electrolyte inventory. A carbonate analysis at the end of testing showed only 5% conversion of the KOH to carbonates which does not account for this performance response. A reduction in cell electrolyte inventory would occur with transfer of electrolyte to the PWR unit. However the endurance period of satisfactory operation on TCP-4 is double previous experience with cells containing wettable hydrogen fields.

Test results from TCP-4 indicating that electrolyte had transferred to the PWR unit are inconclusive. Interpretation of the performance data could have been influenced by the possibility of a low initial electrolyte fill weight, reproducibility of the lightweight cell hardware or a hydrogen over pressure during the endurance test. Each of these factors might have contributed to a reduction in cell electrolyte inventory. Further testing will be required to confirm the non-wettable flow field hypothesis and correct the problem which has limited operating life of passive water removal cells.



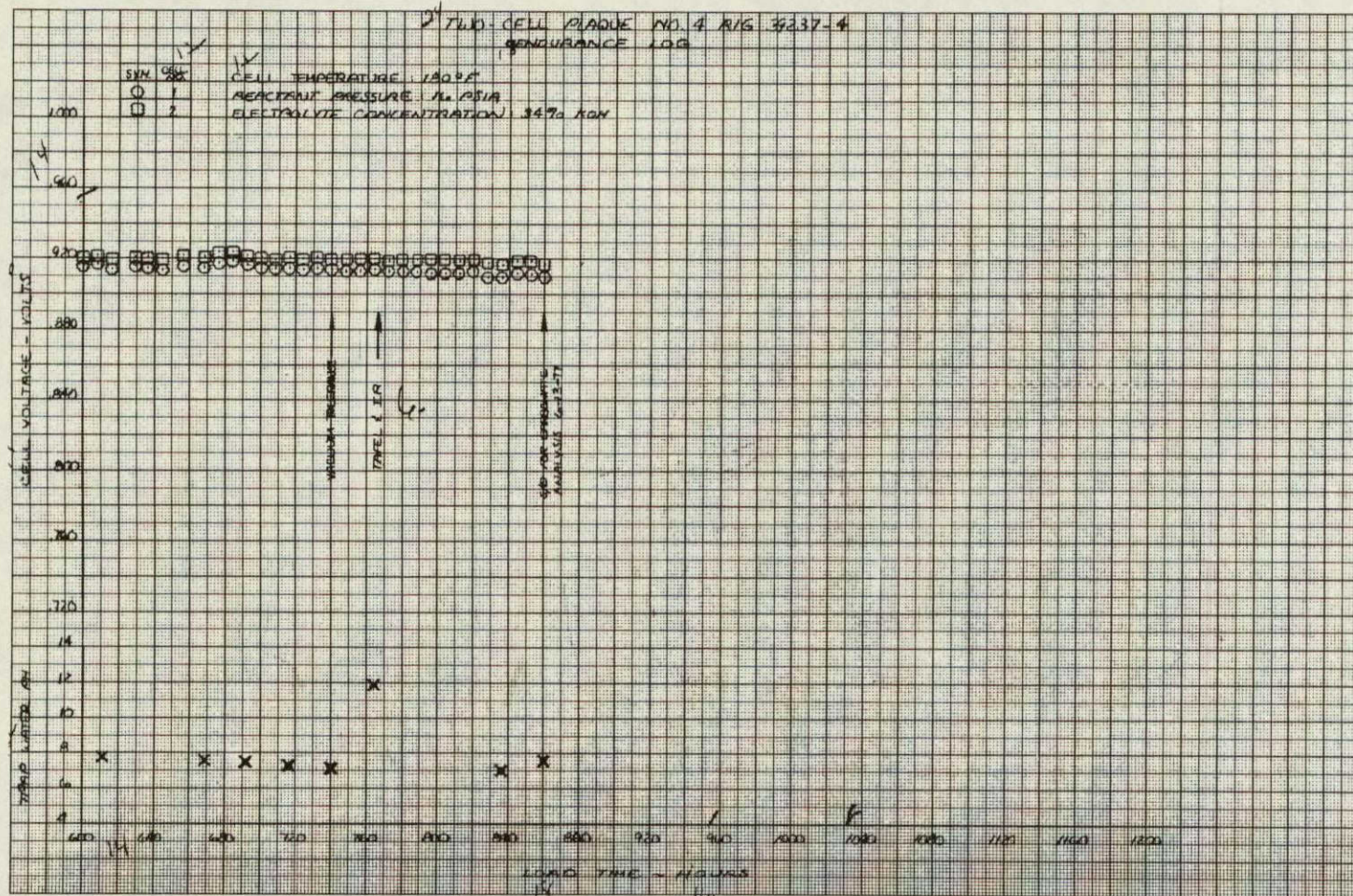


Figure 40. Performance History, Two-Cell Plaque No. 4 (Sheet 2 of 2)

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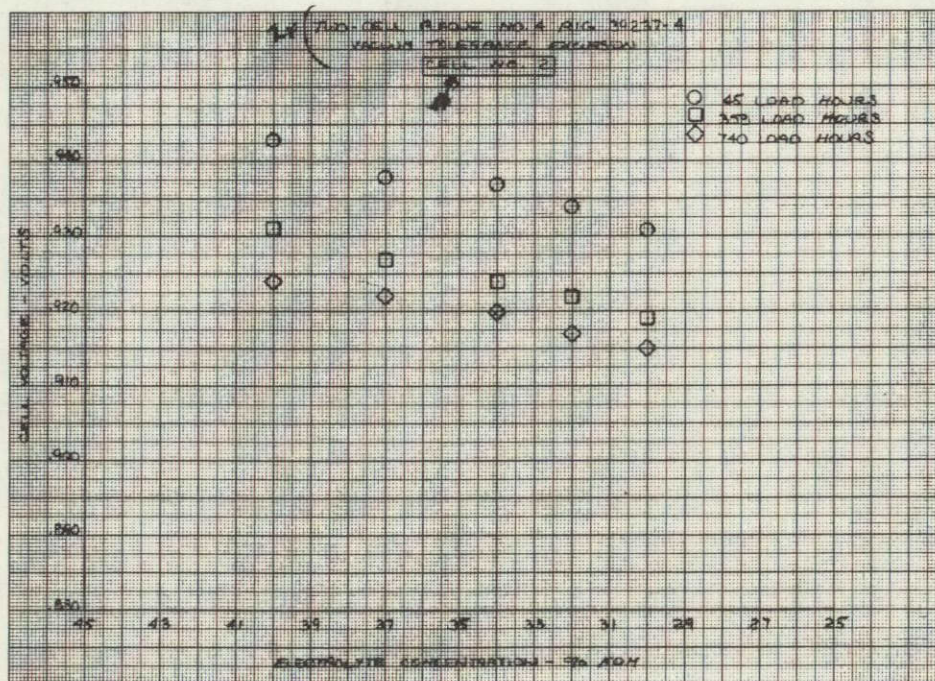
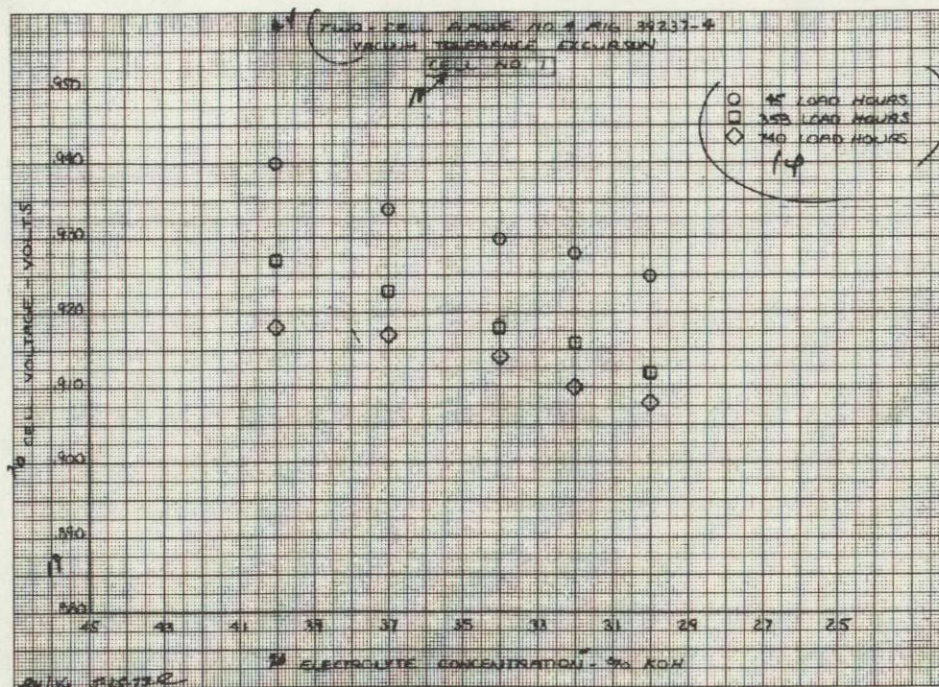


Figure 41. Electrolyte Excursion Data, Two-Cell Plaque No. 4

Figures 42 and 43 show the oxygen Tafel test data and cell IR measurement at the start and end of the endurance test. As shown there was no change in cell IR. There was only a 5 mV reduction in cathode activity while the total diffusion losses at 100 ASF (107.6 MA/cm<sup>2</sup>) had increased by 15 mV.

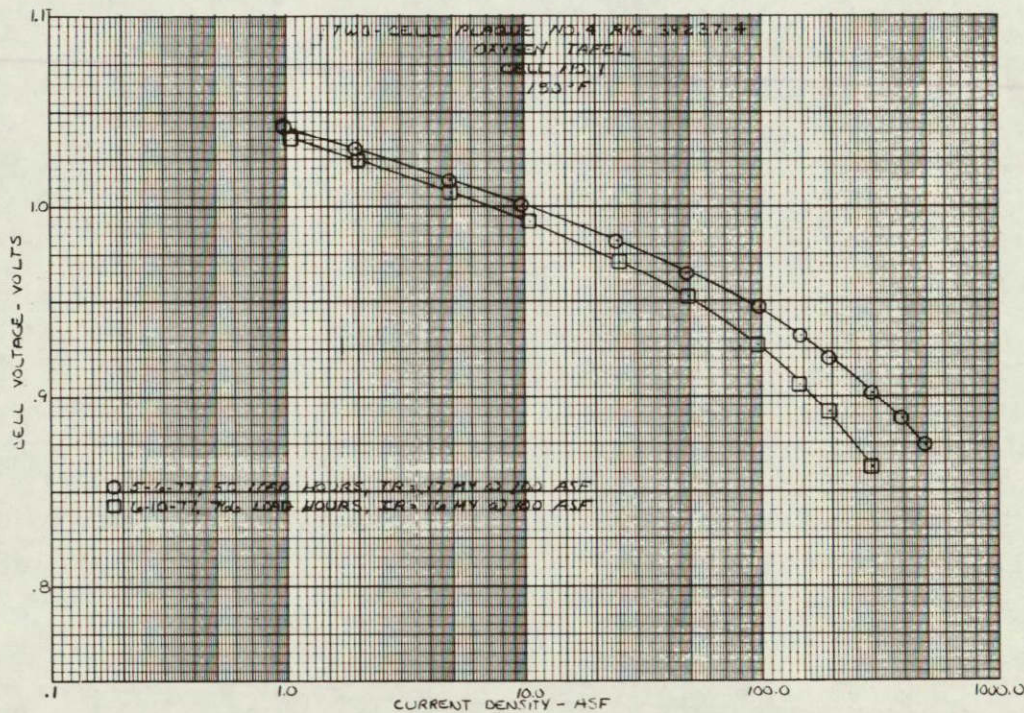


Figure 42. Oxygen Tafel Data, Cell No. 1, Two-Cell Plaque No. 4

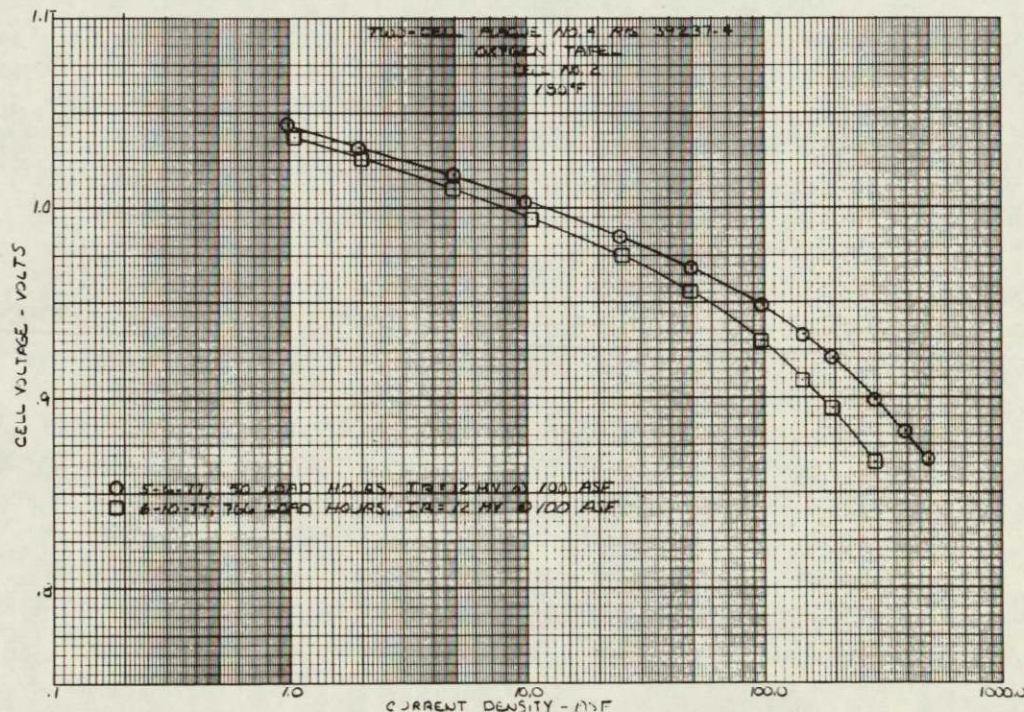


Figure 43. Oxygen Tafel Data, Cell No. 2, Two-Cell Plaque No. 4

## APPENDIX C

## THERMAL CHARACTERISTICS TEST

## Introduction

The test objective of the Lightweight Powerplant Coolant Rig as outlined in Table VI, was to substantiate the coolant to cell temperature gradient model. This temperature gradient model is an integral part of the Lightweight Powerplant analytical simulation which was utilized in establishing the powerplant design table.

## Conclusions

- The test data indicates that the coolant to cell temperature difference was within 1°F (.56°C) of the analytical temperature gradient model over the Lightweight powerplant load range.
- The test results indicate that there was a minimal effect of coolant flow upon the coolant to cell thermal gradient in the flow range of 50-80 PPH/cooler (22.7-36.3 Kg/Hour per cooler).

## Recommendations

- The temperature gradient model in the Lightweight Powerplant analytical simulation at the design coolant flow should remain unchanged as that model is consistent with test experience.
- Additional data should be obtained to corroborate the cell temperatures revealed by this test by installing thermocouples on a future cell which will operate at Lightweight Powerplant loads.

## Discussion

The test program outlined in Table VI consists of a parametric investigation upon cell to coolant  $\Delta T$  of variations in simulated cell waste heat and coolant flow. A cross section of the test rig along with an identification of the individual components is presented in Figure 44.

The test was conducted on 12 August 1976 with 7.8 hours employed in completing the program. A rig checkout was conducted on 6 August 1976 which involved 5 hours of testing. None of the temperature data obtained during the checkout test was utilized as the conditions are of questionable thermal stability.

TABLE VI  
LIGHTWEIGHT POWERPLANT COOLANT TEST PROGRAM

Test Objective: To substantiate the Lightweight Powerplant temperature gradient model

Test Program Outline

<u>Test Sequence</u>	<u>Cell Simulator Heater Power - Watts</u>	<u>Coolant Flow Per Cooler</u>	
		<u>lbs/Hr</u>	<u>Kg/Hr</u>
1	80*	80	36.3
2	80	50	22.7
3	80	150	68.0
4	40	50	22.7
5	40	80	36.3
6	150	80	36.3
7	150	150	68.0

Coolant Inlet Temperature 180°F (82.2°C)

---

\*Equivalent Lightweight Powerplant 3.5 kW, 2500 Hour Performance Level

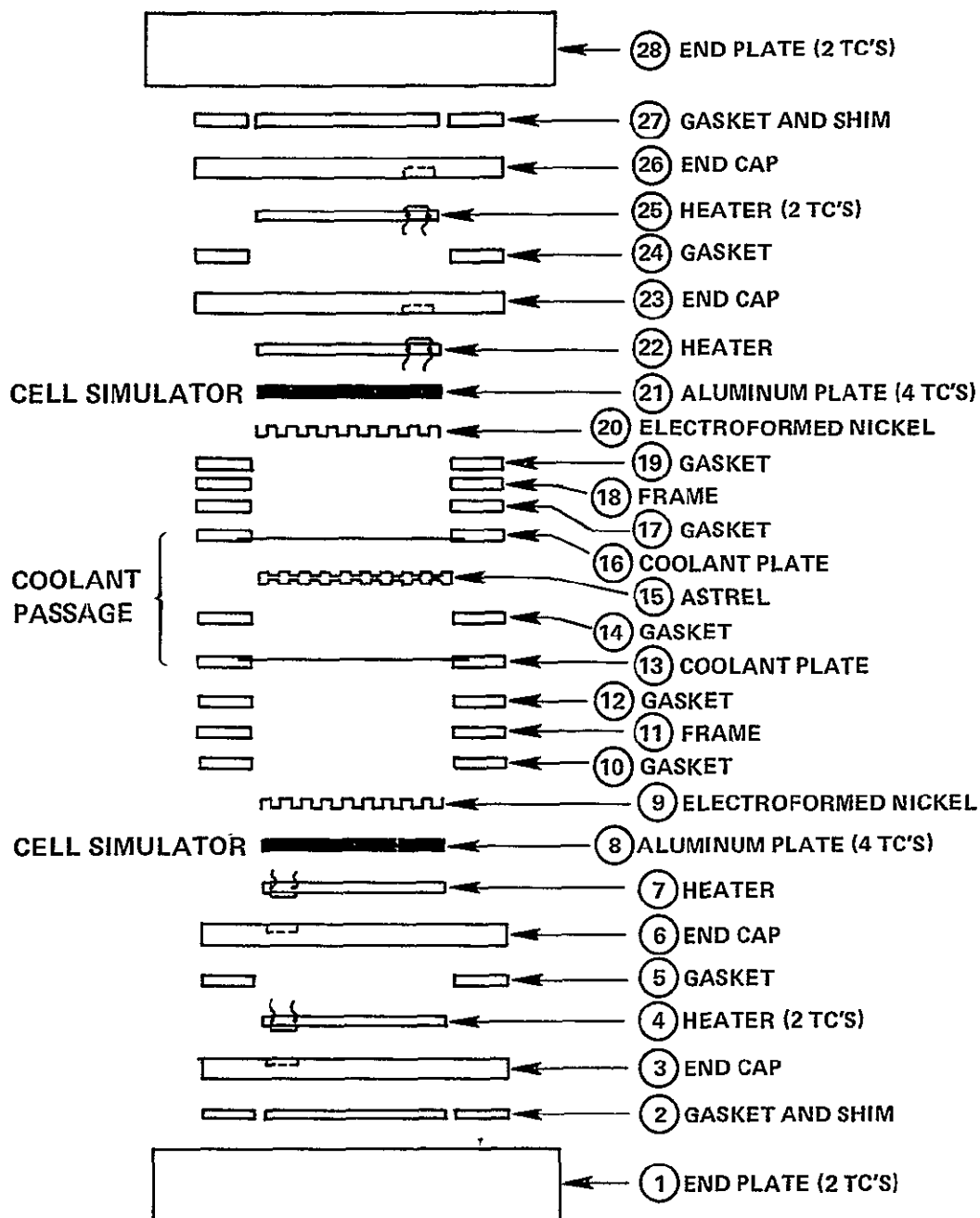
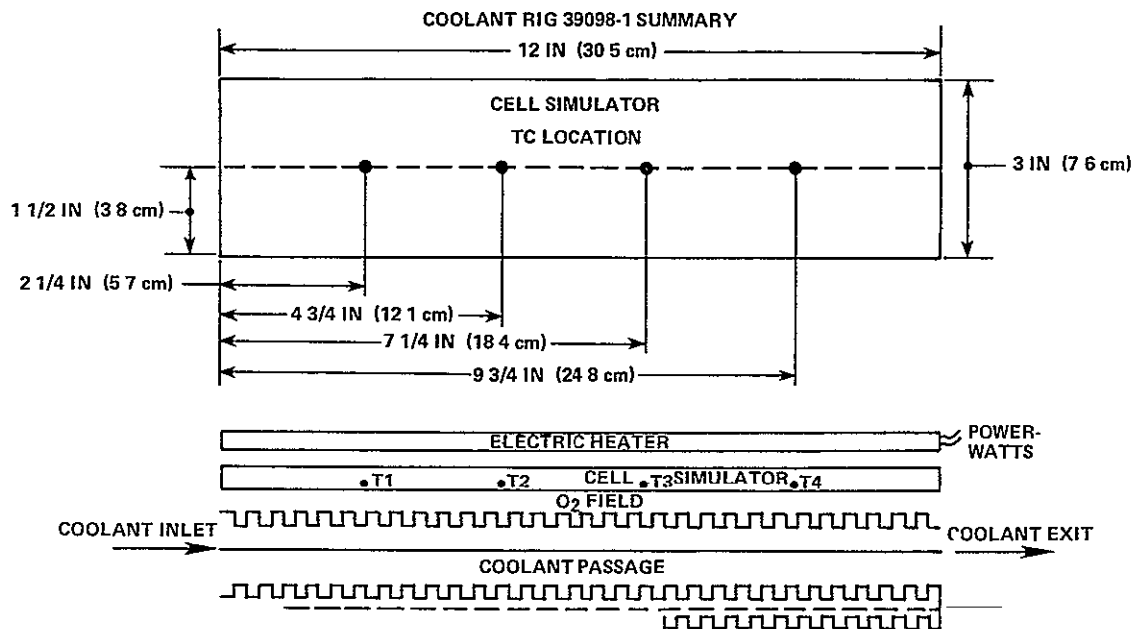


Figure 44. Coolant Thermal Gradient Rig

A summary of the test data and identification of the location of the various cell simulator thermocouples is presented on Figure 45. The cell cooler shown schematically is consistent with the current Lightweight Powerplant design. The thermal gradient identified was arrived at by averaging temperatures T3 and T4 and subtracting that average from the coolant exit temperature. Verification of the thermal gradient at the coolant inlet was problematical as T1 was located 2-1/4 inches (5.7 cm) inboard of the coolant inlet thermocouple.



HEATER POWER WATTS	COOLANT PASSAGE FLOW		COOLANT TEMPERATURE - °F		SIMULATOR TEMPERATURES - °F				COOLANT PASSAGE ΔP	
	lbs/Hr	Kg/Hr	Inlet	Exit	T1*	T2*	T3*	T4*	PSI	N/cm <sup>2</sup>
79.13	84	38.1	182 (83.3°C)	204 (95.6°C)	200.5 (93.6°C)	208.5 (98.1°C)	215 (101.7°C)	215.5 (101.9°C)	2.5	1.7
76.14	50	22.7	181 (82.8°C)	217 (102.8°C)	206.5 (96.9°C)	216 (102.2°C)	229.5 (106.9°C)	227 (108.3°C)	1.3	0.9
77.33	152	68.9	179 (81.7°C)	192 (88.9°C)	191.5 (88.6°C)	195 (90.6°C)	198 (92.2°C)	199 (92.8°C)	7.1	4.8
39.75	50	22.7	179 (81.7°C)	199 (92.8°C)	194.5 (90.3°C)	199 (92.8°C)	104 (40°C)	205 (96.1°C)	1.5	1.0
40.02	82	37.2	181 (82.8°C)	193 (89.4°C)	191 (88.3°C)	194 (90°C)	198 (92.2°C)	198 (92.2°C)	2.7	1.9
150.08	82	37.2	181 (82.8°C)	224 (106.7°C)	216 (102.2°C)	229 (109.4°C)	240 (115.6°C)	241.5 (116.4°C)	2.75	1.9
150.08	152	68.9	180 (82.2°C)	204 (95.6°C)	201.5 (94.2°C)	209 (98.3°C)	215.5 (101.9°C)	218 (103.3°C)	7.4	5.1

\*Average of 2 Thermocouples

Figure 45. Cell Simulator Test Configuration

The parametric data obtained during testing is presented on Figure 46 compared to the Lightweight Powerplant analytical simulation. As shown at the Powerplant 1333 PPH (604.7 Kg/Hr) coolant flow which is a cooler flow of 78.4 PPH (35.6 Kg/Hr), there is reasonable agreement of the simulation model with test experience.

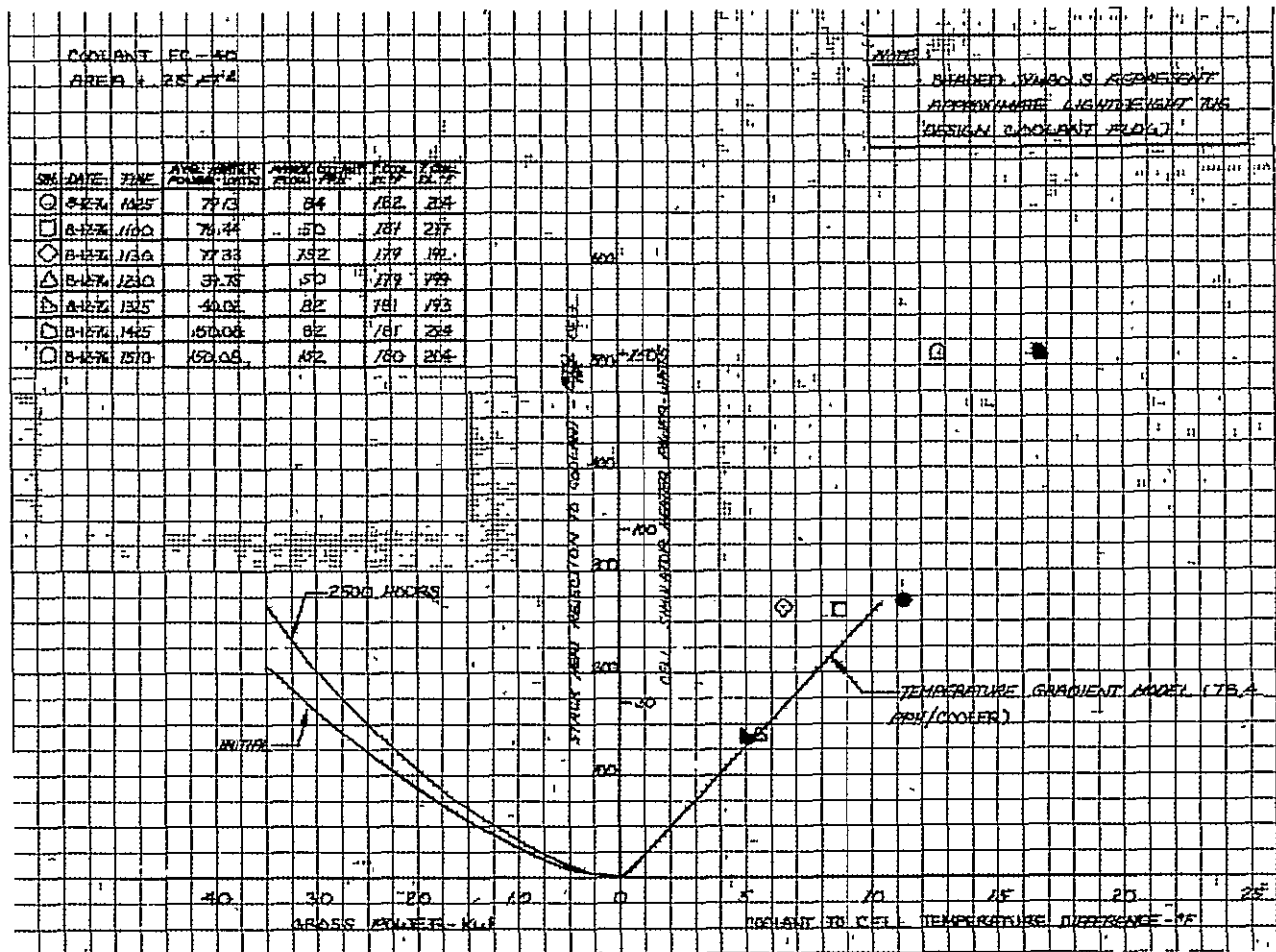


Figure 46. Coolant to Cell Temperature Gradient Model

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16 Abstract This contract was the final one of a series of contracts with the long-range objective to reduce weight, extend life, and improve the performance characteristics of alkaline fuel cells for future space power systems. A unique feature of the advanced technology cells fabricated and tested under these contracts is the capability to evaporate the product water formed during the energy conversion reaction directly to space vacuum. A fuel cell powerplant incorporating these cells does not require a condenser and a hydrogen recirculating pump-water separator to remove the product water. This simplifies the fuel cell powerplant system, reduces weight and reduces system parasite power.  During this program, six, 1/4 ft <sup>2</sup> (232.3 cm <sup>2</sup> ) active area single cells were fabricated and performance tested. In addition, endurance evaluation of a single 1/10 ft <sup>2</sup> (92.9 cm <sup>2</sup> ) area cell initiated under NAS 3-19778 was continued. Also a two-cell plaque containing 1/10 ft <sup>2</sup> (92.9 cm <sup>2</sup> ) area cells was fabricated and endurance tested.  A 1/4 ft <sup>2</sup> (232.3 cm <sup>2</sup> ) active area cell configuration was identified where the performance effect of operating on propellant purity reactants was very small. This cell configuration has been incorporated into the design of a small lightweight power section sponsored by a Marshall Space Flight Center contract. A 1/4 ft <sup>2</sup> (232.2 cm <sup>2</sup> ) active area single cell completed over 5000 hours of endurance testing.  Endurance testing of single cells and a two-cell plaque confirmed that the incorporation of a Teflon hydrogen flow field between the cell and product water removal unit retarded apparent electrolyte transfer which had limited the operating life of past cells. At the conclusion of this contract, 7824 hours of single cell and 859 hours of two-cell plaque testing were completed for a total of over 120,000 hours of testing during the entire program.					
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